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TO THE MEN
OF OUR TIME AND COUNTRY WH
HAVE ENCOURAGED TH
IN ALL DEPARTME

THE STUDY

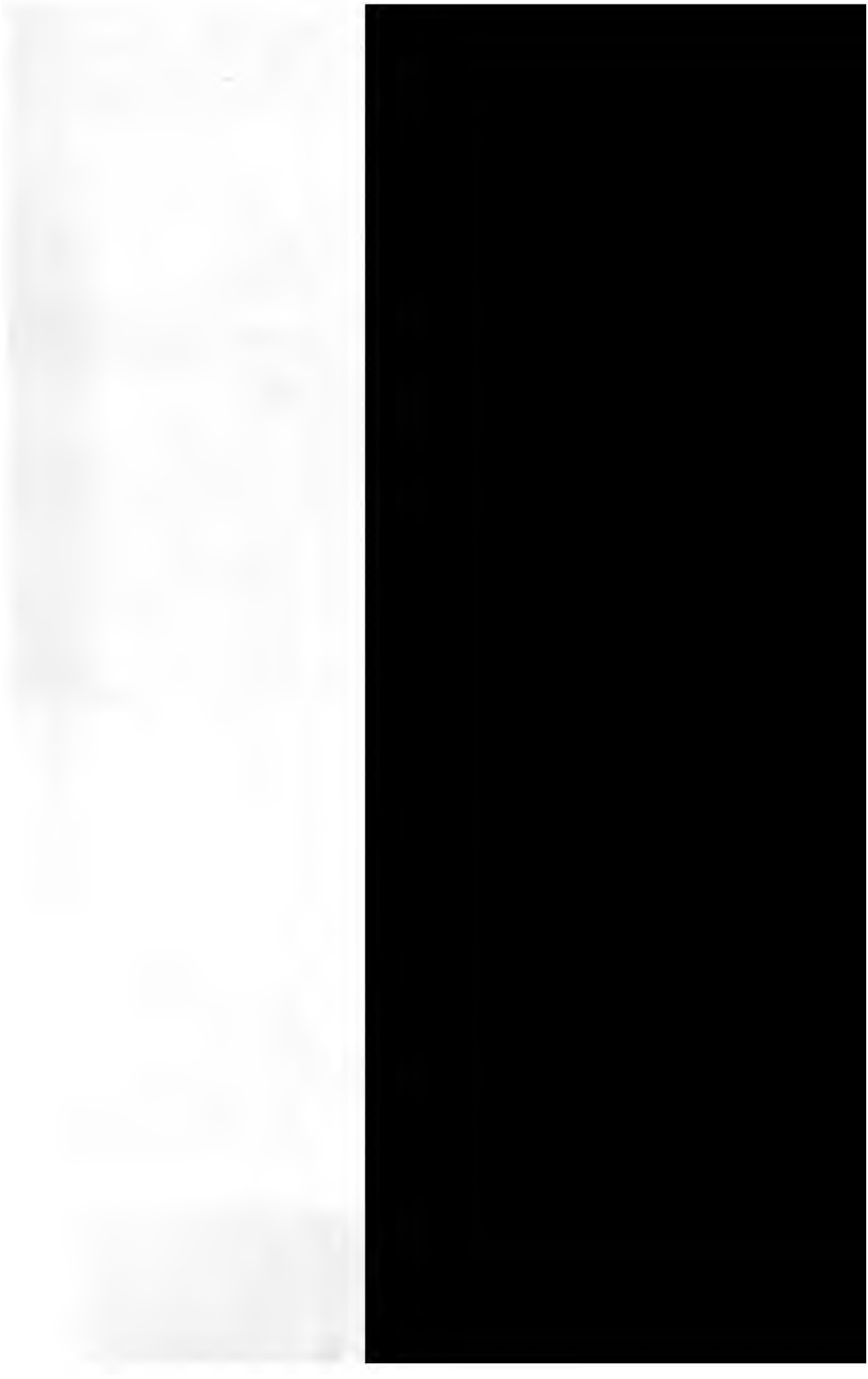

PLATE I

THE GREAT NEBULA IN *Andromeda*

Photographed with the 24-inch reflecting telescope of the Yerkes Observatory (

THE STUDY
EVO

AN ACCOUNT OF S
OF ASTROPH

GEORGE

FORMERLY OF THE DEPARTM
NOW DIRECTOR OF THE

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SECOND S

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I

As first planned, this
handbook to the Yerke
regarding the observator
visitors received there an
explanation of the purpo
methods employed. Rem
connected with the organi
Observatory caused a mo
adopted the plan of descr
tigations, laying special s
employed, in the hope of
of stellar evolution is stu
crete illustrations drawn,
ence, and the desire that t
to visitors at the Yerkes
are sufficient reasons, I t
portion of space devoted t

The omission of such
of temporary and variabl
cussions of evolution as
and Pickering's photomet
the researches of the lat
various types; Campbell's
and, to mention no other w
graphic method of determ
indicate that I have made
problem of stellar evolutio
an adequate description of
physics. The various res
arbitrarily, in some cases

acquaintance with the facts than because of their i
importance. I trust, however, that although this me
treatment has necessarily resulted in a fragmentary
tion of the subject, the book will serve to show h
problem of stellar evolution is attacked along con
lines, leading from solar, stellar, and laboratory in
tions.

I wish to express my thanks to Sir William Hugg
Messrs. Adams, Ellerman, Olmsted, and Ritchey
Mount Wilson Solar Observatory; to Professors B
Burnham, and Frost of the Yerkes Observatory; to P
Campbell of the Lick Observatory; to Professor Pi
of Harvard College Observatory; to Mr. Abbot of the
sonian Astrophysical Observatory; to Professor Lor
Emerson McMillin Observatory; and to Professor
Mr. Jewell of Johns Hopkins University, for phot
which appear in the plates. I am also indebted
Astrophysical Journal and the *Publications of the*
Observatory for many cuts, and to Messrs. Tickno
for permission to reproduce Langley's drawing of a
sun-spot. I am under special obligations to my co
Mr. Ellerman, to whom are due most of the phot
of instruments, buildings, and landscapes which ap
the plates, besides many of the solar and stellar phot
taken from our joint papers in the *Astrophysical*
and elsewhere.

G. E

PASADENA, CALIFORNIA
November, 1907

C

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I. The Problem of
II. The Student of t
III. The Sun as a Ty
IV. Large and Small
V. Astronomical Pho
VI. Development of t
VII. Elementary Princ
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sition of the Sun
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XXI. The Meteoritic A
XXII. Does the Solar H
XXIII. The Construction
scope - -
XXIV. Some Possibilities
XXV. Opportunities for

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C

THE PROBLEM

It is not too much to
investigators toward rese
since the publication of t
not only of biological re
domain of the physical
formerly content to stu
regard to their larger re
a wider view. As a con
scientific research have
student, who could see in
bones, now finds each fr
part it plays in a genera
clear. The color and st
minute modifications wh
another, take on new si
dences of development.
or to anyone who finds
beauty of form, is quite
dent whose interest is n
from lack of technical k
these matters are trivial a
of science, such minor
light. Their true signi
importance of studying t
now requires no demonst

In astronomy the ide
early period. In a crud
of the earliest peoples in

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origin of the Earth and its inhabitants. On a r
plane stand the speculations of the Greek philo
of those who have followed them in the centuri
our own time. All schools of astronomers, deal
instances with purely philosophical and theoretic
tions, and in others basing their conclusions
facts of observation, have sought in their turn to
origin of the solar system and the larger relati
obtain in the universe as a whole. In the eighte
these speculations reached their climax in the
pothesis of Laplace, which still remains as the
attempt to exhibit the development of the s
Attacked on many grounds, and showing signs
that seem to demand radical modification of Lapla
ideas, it nevertheless presents a picture of the
which has served to connect in a general way a n
vidual phenomena, and to give significance to
isolated facts that offer little of interest without t
tion of this governing principle.

It will be seen, therefore, that the idea of e
development is by no means new to the astronon
may nevertheless be maintained that it has occu
important position since Darwin published his
In 1859, the very year of the publication of th
Species, Kirchhoff first succeeded in determining
composition of the Sun by the aid of the spectro
fundamental discovery marked the entrance of
ment into the field of astronomical research and
on a firm basis the new science of astrophysics.
tance of spectroscopic investigations in their rel
evolution was soon made clear. Within a single
study of stellar spectra by Huggins, Rutherfurd,
had shown that the stars may be divided into sev
characterized by distinctive peculiarities in the

emission and marking def
of development. Followin
came the capital discovery
of the nebulae, and the rel
to the stars which they ens
luminous gas it appeared
origin, taking form after l
processes regarding which
defined. Belief in such a
greatly strengthened throu
tions, and especially throu
of 120,000 nebulae strewn
distinctly spiral in form.
coming at the end of the
materials for those who s
nebular hypothesis, to prov
tion of the development of

We are now in a positi
as that of a single great pr
of the stars in the nebulae
and complex sciences that
for the phenomena of life,
society composed of human
of all natural phenomena
must begin with a study o
enough the Earth to permi
knowledge thus derived m
on the nebulae, and in the
vations of those stars whi
stellar existence. Accordi
development attained by t
of decline. After it come
last stages of luminous ste
light due to continued co

altogether from the astrophysicist's study those dyir which represent a condition lying between that of a g sun and a dead planet like the Earth or the Moon. T one of its many remarkable properties, the spect enables us to detect the presence, and sometimes t mine the dimensions, of vast bodies which have result the cooling of former suns. It will be the object book to show how the student of astrophysics atta problem of stellar evolution, through the develop special instruments and methods of research, and th mulation and discussion of observations.

It must not be forgotten that such a study compris the earliest and simplest elements in the general pro evolution. The province of the student of astrophys be said to end with an understanding of the product planet like the Earth. It remains for the geologist to the changes which the surface of the Earth has unc since the constructive process left it a rocky crust. T ditions which brought about the formation of the oce effects of the long-continued action of winds and wa the vast changes in surface structure that have result internal disturbances and the operation of volcanic p ena, afford limitless opportunity to the student of e in this other aspect. Closely related to these chang presenting difficulties far greater than those experie the astrophysicist, comes the problem of accounting origin and development of plant and animal life. Th ervation of the earlier forms of life, principally thro agency of sedimentary deposits, affords the paleontolo means of connecting the links in the evolutionary Thus we are brought to our own era, where countless objects continue to supply material for new inquiries in the examination of existing species and their relatic and in those experimental researches on variation whi

such promising opportuni
tionist may secure data f
immediate domain of th
activity where still greate
may seek to trace out evid
the mental and moral re
countries and of many ge

It is a noteworthy fact,
gators who find special in
and unoccupied fields, that
opments of recent years
which lie between the b
sciences. Thus the unio
opened up the extensive
advances of the greatest v
way the application of ph
of physical chemistry to th
has resulted so successfu
remarkable developments
the introduction of physic
observatory, transforming
into a laboratory, where th
in the solution of cosmica
is common to these and
science affords striking pr
An investigator who has
methods of a department
played little part, may th
powerful means of advanc

The suggestive value,
ments, of any species of sci
methods and principles
time than ever before.
which can find no direct

frequently capable of suggesting modifications or ad
involving related principles. The development an
new methods is quite as likely to advance a subje
prosecution of extensive investigations by existing
For this reason the investigator is ever on the alert
and utilize suggestions derived from any source.

The interest of the student of astrophysics is n
confined simply to celestial phenomena. For astr
has become, in its most modern aspect, almost an
mental science, in which some of the fundamental
of physics and chemistry may find their solution. T
may be regarded as enormous crucibles, in some
terrestrial elements are subjected to temperatures a
sures far transcending those obtainable by artificia
In the Sun, which appears to us not merely as a
light like the stars, but as a vast globe whose eve
can be studied in its relationship to the general pr
the solar constitution, the immense scale of the ph
always open to observation, the rapidity of the chan
the enormous masses of material involved, provide th
for researches which could never be undertaken in te
laboratories. Hence it is that astrophysics may equ
be regarded as a branch of physics or as a branch o
omy. A telescope may be defined as an instrun
revealing celestial phenomena, or it may be likene
lens which the physicist uses in his laboratory to con
the light of an electric spark on the slit of his spect
To the student of astrophysics whose interests are
fined to a single branch of science, the subject is
make a double appeal, no less strong on the phys
chemical than on the astronomical side.

In entering upon our consideration of the study
development, we may think of the subject in eithe
two ways. Some will prefer to regard it as the gene

lem of stellar evolution, i
verse at large. But othe
the question as an inv
through analogies afford
growth, from its origin
which, though not yet wr
in the life-histories of th
ever standpoint, the tas
same, since in either case
development, and decay.

It must, of course, be
stellar development ordin
time would be far too sho
to be observed in a star.
fade rapidly away; but t
tion, typical of some cat
course of change. The s
ance leaves little doubt
stant change of form, are
so vast a scale, that no a
been detected in photog
intervals of many years.
sand years is but a day,
stellar histories upon ana

Fortunately, the data
histories are easily found
who enters a forest of
what stages the trees hav
condition. He cannot w
tree go through its long
he may find acorns, son
Others have given rise t
lings are at hand to sho
saplings to trees is an ea

form of dead limbs and branches, the first evidences reaching its full in fallen trunks, where the hard wasting to powder.

Scattered over the heavens are millions of st representing a certain degree of development. T forms of the nebulae tell us of stellar origins; tl yellow, and red stars illustrate the rise and decline life; and the Earth itself affords a picture of w remain after light and heat have been extinguished

C

THE STUDENT

THE traditional conce
applicable (with sundr
instances, does not accu
evolution. According t
after the setting of the
whose summit he gaze
long watches of the nigh
telescope tube, perceive
sweeps with his vision th
verse. The lineal desce
of the Chaldeans, he dwe
the ordinary concerns o
thoughts with celestial n

Now there can be no
lution brings a degree o
would be difficult to sur
excitement that comes t
upon an unknown land, t
all belong to the succes
gazing through a telesco
taking work of modern
photographic plate, is sti
ging phenomena, and im
to the alert and careful
the surprise and delight
spots on the supposedly i
little instrument, much l
could reveal none of th

detail that are at once the joy and the despair of pre
sun-spot observers. But he had discovered a
important fact, the basic principle of the science
physics: he had shown that with suitable optical
physical structure of the heavenly bodies might be
gated. Prior to this time astronomy had concern
only with the positions and motions of the stars
became evident that each of these luminaries might
peculiar and distinguishing phenomena worthy of
searching investigation. Discovery followed disc
rapid sequence. The mottled face of the Moon,
without meaning, was suddenly revealed in uns
landscapes of valley, plain, and mountain, resem
curious degree, the variegated surface of the Earth.
who had seemed to travel alone through the hea
found to possess four companions, whose revolutio
him forcibly suggested the revolutions of the plane
the Sun. The mysterious *ansae*, inclosing betwe
the globe of *Saturn*, were soon made out to be t
conspicuous elements of a vast incircling ring, unl
thing of earlier experience. With the growth of
scope more marvels were brought to light, until it se
sound reason, as though the universe would never
yield new knowledge to the explorer of its boundles

Thus was established that conception of the ast
that still persists, long after a new astronomy has c
being. Gazing through a telescope, as has been sai
competent to bring discoveries; for change is the ver
of celestial phenomena, and persistent watching mu
important facts, on which broad generalizations
founded. But the eye and the telescope have beer
mented by various instrumental aids which, in thei
plication, have transformed the occupations of the ast
The micrometer, in its application to the accurate

ment of place and form, pe
are beyond the perceptio
its precise determinations
whose light never varies a
The photographic plate,
scope, has proved itself t
retina, in that it is capab
the invisible radiations re
hours. Finally, to menti
new adjuncts, the spectr
revolutionary principle in
cal and physical analysis

Hence it is that the
does not correspond to the
His work at the telescope
keeping a star at the prec
or on the narrow slit of
and nebulae, or their spe
the photographic plate.
and most of his discoveri
been developed, and are s
ment under the microsco
methods of calculation or
invention of new instru
time may be spent in the l
placed at his disposal by
ous conditions of temper
the stars, and watching t
these uncommon environm
and promising means of re
tion, he would advance i
devote himself to the des
ments, to supplement the
newest phases of physic

countless applications of electricity, the methods of engineering, and the practical details of workshop p his interest in these things of the world is likely to l as broad as that of the average man. His sympat research in every branch of science must incre strengthen as his conception of the great problem o tion is developed by his own investigations of its phases. And the pleasure and enthusiasm derived f studies must become, not like the vague passion of t tic, whose inability to see clearly leads him to pursue gods, but such as every successful searcher after tru experience, whether he deal with the vast dimensi distances of the heavenly bodies, or with the minute less marvelous phenomena of microscopic life and fo

Now, while it cannot be too strongly emphasized student of stellar evolution can have no sympathy v mystic, whose habit of thought must be the very ar of his own, yet it is true that the imagination, when p exercised and controlled, is to be regarded as his bes progress. The question of control is so important may well be mentioned first. For nothing has do injury to science than the play of imaginations subje control, on the part of men who enjoy in the public p rank of scientific authorities. Thus great sun-spots the innocent cause of earthquakes or tornadoes, not t of their effect upon the price of wheat. Comets, o unerring portents of war and pestilence, still carry the of conflagration, and threaten at each apparition to the Earth. Mystic properties are ascribed to the c the universe, and a well-known planet, because it i rectly assumed to be stationed there, is dogmatically a to be the only possible abode of human life. There field here for humor and amusing speculation, as the of the "Moon Hoax," and other more recent writer

shown us. But humor is
ciamentos go forth in the
by a host of intelligent per
supposed authorities have
tific methods. Thus there
and a popular demand
satisfied by acquaintance

But though dangerous
tion, when rightly exer
astronomer. His dreams
ments, and his work of to
a plan projected years ag
generations hence many o
his time are to be replace
vision to obtain some gli
the obscurities of the fut
surrounded by lenses and
the other elementary appa
light, he cannot fail to e
the intelligent recognitio
optics might suffice to co
new instruments of enor
advance in engineering or
dreams of new possibilitie
tion of his telescopes or th
reads of discoveries in ph
mind is busy in its endeav
the solution of long-standi

But here, again, we see
a multiplicity of interests,
imagination, the danger
With scores of problems s
and with attractions on ev
in its apparent possibilities

is to choose wisely. It is not a question of sear something to do, but of picking out those things most worthy of pursuit. Here the importance of definite and logical plan of research becomes appare a plan may involve a single investigation, contin systematic lines over a long period of years, or it prise several investigations, carried on simultanec a large observatory each piece of work acquires importance if it is selected, not at random, or solel of its intrinsic value, but rather because of the pa in a single logical scheme of research. Its intrins tance need not be in the least diminished by its re to other work, while the illumination which its resu the other investigations of the scheme can harc improve them, and may even reveal the chief sourc meaning. Moreover, the same research, if carriec where, might prove of small value, in the absenc suggestions and modifications as are sure to come related investigations. We shall have occasion to this question in discussing a plan of attack on tl problem of stellar evolution.

CH

THE SUN

BEFORE proceeding to
discussion, let us examine
with which we are to de
ments of relationship wh
describe more fully. Let
a single object, which we
objects less easily observe
from the Earth.

The photographic repr
Sun, as seen with an ordi
judged from this picture
luminous sphere, brighte
circumference, and marke
tributed over the surface.
be seen that there are cer
easily noticed near the ed
the well-known sun-spots
the bright regions are
known since the inventio
eclipse, when the bright
dark body of the Moon,
usual brilliant illuminatio
heights of several hundre
from a continuous sea o
the Sun. These are the
mass of flame from whi
(Plate III).[1] Extending

[1] See the remarks on anomalou

sometimes to a distance of millions of miles, is the cor
which shines with a silvery luster somewhat inferior in bri
ness to that of the full Moon (Fig. 2, Plate IV).

An analysis of the light of the Sun, made with the spec
scope, has shown the presence of the vapors of iron, sodi
magnesium, calcium, hydrogen, and many other substa
known to us on the Earth. In fact, it has been remar
that if the Earth were heated to the temperature of the S
the light emitted by its vapors would resemble closely, w
analyzed with the spectroscope, the light emitted by the S
Thus the chemical composition of the Earth and the Su
much the same, although we have evidence of the existe
in the Sun of a large number of substances not yet found
the Earth. This same means of analysis has led to the
covery that the chromosphere, and the prominences wh
rise out of it, are composed of the vapor of calcium and of
light gases helium and hydrogen. The sun-spots, too, h
also been found to have a characteristic chemical com
sition; while the corona emits rays which probably indi
the presence in it of very light and tenuous gases.

Observations of the Sun, continued without interrupt
for more than half a century, have shown that the spots
not constant in number, but vary in a characteristic wa
a period of about eleven years. At times of sun-spot m
mum the surface of the Sun is marked by large numb
of spots, which are found on attentive observation to be
scene of great activity, and frequently the source of the n
violent eruptions. At this period the prominences are la
and abundant, and testify to the general condition of distu
ance by exhibiting, from time to time, eruptive phenom
on a very large scale, in which great masses of gas h
been known to shoot upward with velocities of hundred
miles a second. With the passage of time these evidence
disturbance and activity become less and less marked, u

finally, during the minim
for months together ma
The prominences also be
phenomena, so common
rarely to be observed at
undergoes changes in fo
teristic, and show a defi
period.

So much for the Sun a
We are now led to inqui
among the other heavenl
removed to the distance o
would then be reduced i
passed by that of many
would still remain one o
the heavens. The plan
wholly beyond the range
powerful telescopes. Th
yellowish, and it would b
certain stars which also sh
troscopic analysis of the
presence in their atmosph
the Earth; indeed, the
them can be shown to be
Sun. On account of its
would be reduced to a mi
the other stars, and the s
other phenomena would
reason, such phenomena,
other stars, are hidden f
fore conclude that the Su
chemical composition and
other stars in the heavens
of these objects.

A very casual acquaintance with the stars, based
naked-eye observations, is sufficient to make one fa
with the fact that they differ from each other as mu
color as they do in brightness. Such objects as *Sirius*
with a bluish-white light, whereas *Arcturus* is yellowis
the Sun. *Antares*, in the *Scorpion*, is a fine example
red star, and with the telescope smaller stars may be
of a deeper red color. Spectroscopic study of these va
classes of stars shows in the clearest way definitive pecu
ties, which may form the basis of a system of classific
Indeed, we apparently find ourselves in the presence of
in every stage of growth, from the earliest, as repres
by the bluish-white objects, to the latest, typified by th
stars[1] (Fig. 1, Plate IV). Intermediate in point of dev
ment are yellowish stars like the Sun.

In various parts of the heavens clusters may be obse
in some of which the stars are widely scattered, as i
Pleiades, while in others they are densely packed toge
so closely that several thousand stars may sometimes be
within an area so small that to the naked eye they appea
a single hazy star. Since we find clusters of every degr
density, and since the stars in the heart of some of
clusters are too close together to be separated by the
scope, the question long ago arose whether the neb
which seem to resemble luminous clouds in the heaven
to be regarded as star clusters so dense as to be be
telescopic resolution. It was not until the spectroscop
been applied by Huggins (see p. 54) that this questio
finally settled. It then appeared that some of the nebul
least, are vast masses of luminous gas, and that the
therefore not composed of separate stars. It might th
inquired what part in the scheme of evolution such ne
play. It will be shown in the course of this book that

[1] See the cautionary remarks on p. 198.

exists between stars and ne
as to leave little doubt that
through the long-continue
seems probable that the
which stars are made, in
state.

CHAPTER IV

LARGE AND SMALL TELESCOPES

It must soon appear, to one who seeks in the
with unaided vision for evidences of stellar evoluti
but little progress can be made without powerful instr
means. When the nature of the problem is consider
it is remembered that all observations of the stars
made from the surface of a minute body moving thro
midst of the universe, the only cause for surprise will
instruments of sufficient power for our purpose can
structed. The distances of the stars are so enormou
might seem hopeless ever to solve the problem of the
ical constitution, or to analyze them as the chemist
into its elements a substance in his laboratory.

Let us consider what must be accomplished before
even begin to study the subject of stellar evolution.
course of our work we must deal with stars which are
invisible to the naked eye, but are beyond the reach
except the most powerful telescopes. We must find th
of collecting the light from such bodies, not only th
which, if intense enough, could be seen by the e
also those which, because of the structure of the
wholly invisible. After collecting together such r
must subject them to analysis by instruments which
mit us to draw conclusions, both as to the nature
chemical elements present in the star's atmosphere a
the physical condition of these elements, illustrated
pressure and the temperature to which they are su
Although we may never hope to see a star's actu
even in the most powerful telescopes of the future,

than a minute point of ligh
entiating one part of the st
ing, for example, whether
or below that of iron or
luminous clouds, like those
acteristic of the star under
detect their presence, thou
If, as in the case of temp
pressures may produce grea
between the inner and ou
we must learn a way of dis
ascribing them to their tru
necessary precedent to the
determine whether the star
the Earth, and to measure i
great precision.

Moreover, our means of
they shall enable us to inv
physical and chemical pro
those minute peculiarities o
may relate them to other st
in some general scheme of
some means at hand which
nebulae, even though they
by the most powerful tel
given these forms, we must
between the cloudlike nebu
they surround. And the m
the constitution of the stars
the nebulae, thus serving to
which no mere indications
provide.

A refracting telescope
usually mounted at the end

at the object to be observed. In the present c
suppose this to be the Moon. The lens forms a
the Moon at the lower end of the tube, just as tl
camera forms an image on the ground-glass. Ind
scope may be regarded as nothing more or less t
camera, in which a tube is substituted for the ordin
By putting a plate at the point where the image is f
giving a suitable exposure, the Moon may be phc
just as a landscape is photographed with the ca
eye observations, however, the image formed by tl
is looked at through a small lens called an eye-p
image is magnified in the same way, and to the s
as any object would be if looked at with the eye-
as an ordinary hand magnifier. The total magnif
of the telescope, however, of course depends not
the magnifying power of the eye-piece, but also u
of the image formed by the object-glass. The
image is determined solely by the focal length,
from the object-glass to the image. Suppose, fc
we have two telescopes, with object-glasses of the
eter, but of different focal lengths. The one of l
length will give the larger image. If the focal len
that of the other telescope, the image will be twi
With the same eye-piece, therefore, the magnifyin
the longer telescope will be twice that of the sho

We thus see that the size of the image give
scope does not depend upon the diameter of its o
The brightness of the image, however, evidently d
upon the amount of light concentrated in it, and th
with the diameter of the object-glass. If we
diameter of the object-glass, we get four times as
in the image of a star; for the amount of ligh
depends upon the area of the object-glass, and th
as the square of its diameter.

These details are worth
in great measure, the relat
telescopes. There is anot
first importance, which m
telescope is limited, by the
of separating two closely
less than a certain distance
ing power of the telescope,
length or through the use
possibly show them as sep
the fact that the image of
disk, the diameter of the
object-glass. The disk g
grows larger; so it is easy
divide a close double star
star images, which are of s
overlap, as seen in the su
high resolving power of t
dimensions that they appe

Here, perhaps, a word
it is not at first sight ob
smaller in a large telesco
statement would not be tr
These objects are all comp
a moderate magnifying po
most distant planets) as di
visible. The *stars*, howe
that no telescope, howeve
disks. They are mere poi
reason apparently larger, in
always becoming more min
favorable atmospheric cond
instruments.

The *spurious* disks, w

light-waves were infinitely short, appear large in small telescopes, but small in large ones. In the Yerkes telescope, for example, stars separated by only a tenth of a second of arc can be resolved under the best atmospheric conditions. A four-inch telescope cannot separate stars that are less than a second of arc apart, no matter what magnifying power be applied. In such an instrument, therefore, the thousands of double stars whose components are separated by less than a second appear as single stars. In the same way, minute markings, lying close together on the Sun, Moon, or planets, are not separately distinguished in a small telescope, while in a large one they may be seen as distinct objects, provided the atmospheric conditions are sufficiently favorable.

We may sum up the preceding remarks by saying that in all astronomical observations which involve the separate and distinct recognition of very closely adjacent stars, or a knowledge of the most minute structure of the Sun, Moon, or planets, large telescopes must be employed under excellent atmospheric conditions. Furthermore, if it is a question of collecting sufficient light, either for eye observations, or for photography, or for spectroscopic analysis, from an extremely faint star, the great area of a large object-glass or mirror also becomes essential. Nevertheless it will be shown that for many important investigations small telescopes are equal or even superior to large ones.

This brings us to the much-discussed question of the relative advantages of large and small telescopes, regarding which a great deal has been written. On the one hand, we hear the amusing claims of the promoters of the great telescope which was to be the *clou* of the last Paris Exposition. This immense instrument—which does not seem to have been completed, and is now lying unused—was to bring the Moon within the observer's grasp—if he could reach a meter! The light-heartedness of this claim is manifest when it is

remembered that no exis
atmospheric conditions, has
it would appear to the un
miles.

On the other hand, it h
ence, that it is absurd to
inches' aperture east of the
six inches' aperture in th
west of it. This statemen
one which emanated from
unwarranted by the facts
emphasize a conviction th
the eastern part of the Un
suited for large telescopes.
pheric disturbances are the
of the world; we shall hav
in a future chapter. It is
conditions are, on the ave
astronomical observations
United States than east o
cannot be denied that ma
turned out by our eastern
the fact that they are equi
these telescopes would do
conditions goes without s
exist at all, however, if it h
them some thousands of n
leges with which they are

To those who have use
the great advantages of lar
work are well known. I h
exclaim, when looking at J
forty-inch Yerkes telescop
planet with a small telesco

more of detail could he perceive at a single glance. I have seen minute structure on the Moon with this telescope, no trace of which could be made out with a twelve-inch telescope on the same evening. Countless fine bright lines in the spectrum of the chromosphere, which could never be detected with the twelve-inch, are easily seen with the forty-inch. Burnham has separated double stars at the theoretical limit of resolution of the Yerkes telescope, and Barnard has observed the tiny fifth satellite of *Jupiter* when it was beyond the reach of all but the largest existing instruments. When I think of these observations and of Ritchey's photographs of the Moon and star clusters, Frost's and Adams' photographs of the spectra of faint stars, and the no less important results obtained by Schlesinger, Parkhurst, Ellerman, Fox, and others with the Yerkes telescope; and when I remember that most of these observations or results could not have been obtained with a small telescope, I see no possible reason for denying the manifold advantages of large instruments. My illustrations have been confined to observations made with the Yerkes telescope, because of personal knowledge of them. But they could be greatly multiplied if the remarkable work of the Lick telescope and of other large instruments were drawn upon for examples. In the next chapter, through the aid of photography, some of the relative advantages of large and small telescopes will be illustrated.

CH

ASTRONOMICAL PHOTOG

THE emphasis laid in t
of large telescopes must n
telescopes are of little valu
discovered 451 new doub
(Plate V) is sufficient evi
true that small telescopes
classes of work, in which
superiority over large tele
fields. The equipment of
the provision of both large
for use in the investigation
In fact, the characteristic
tory which distinguishes it
tory of one or two instrum
multiplicity of special app
purposes. The day of th
for conditions similar to
development of the innum
machine shop obtain also

The amateur astronom
mind. There is some r
expensive equipments of
to discourage the worker
who has looked at the s
permitted to oppose this p
ing that recent developm
amateur, I am strongly of
for useful work have nev

importance of this subject, due to the high value contributions to astronomy made by amateurs in t has led me to devote a subsequent chapter to oppo for work with inexpensive instruments.

In considering the peculiar advantages of small te in certain fields of research, attention must be calle outset to the important part played by photograph astrophysical work of the present day. The phot plate, through its power of storing up impressions feebly luminous rays, has in most cases an immense tage over the eye. The eye perceives almost at once as can be seen by long gazing at a faint object. photographic plate continues, hour after hour, and night after night, to accumulate impressions, so th sufficiently long exposures, objects far too faint to by the eye with the same telescope are clearly a manently recorded. Moreover, the photographic sensitive to light-waves which are too short to prod least effect upon the eye, and in this power of re objects which otherwise could never be rendered vis matter what their intensity of radiation, the plate pr second great advantage. Because of these and othe of superiority, which far outweigh certain slight defe in some few instances still leave the plate inferior to the photographic method is now exclusively emplo many kinds of observations.

Some of the most important results of astronon been derived from the use of an ordinary camera, just such a lens as is found in the possession of th of amateur photographers. If we take an ordinary and point it on a clear night toward the north pole be found, after an exposure of one or two hours, t stars which surround the pole have drawn arcs of upon the plate (Plate VI). This is due to the fa

the Earth is rotating upo
every star in the sky to a
circle once in twenty-four
in the sky toward which
easy to understand that t
the smaller does this circl
the pole we find the curva
and less, until at the equa

Just such photographs
in astrophysical investig
recording variations in a
shown on the plate by c
But for most purposes it
stars in which they are r
than as lines. To obtain
mount the camera in such
an axis parallel to the E
rate, once in twenty-fou
becomes an equatorial ph
important respect, save i
the largest refractors.

Here, for example, is
Bruce photographic tele
This instrument has a co
made by Brashear from
such curvature as to for
inches distant from the o
will be seen that such a l
highly concentrated imag
crowded close together
picture. If the same len
image ten times as far di
the several elements of t
more widely separated, a

to photograph them, on account of the spreading of amount of light over a larger surface. As will be s the illustration, the tube which carries the lens an graphic plate is mounted in such a way that it may b about an axis parallel to the axis of the Earth by me driving-clock, placed in the upper part of the iron su column. The same mounting carries not only the lens, but also the lens of a guiding telescope, throug the observer watches a star during the entire p exposure, continued, perhaps, for many hours. thus correct any slight irregularity in the motion of scope by certain screws provided for the purpose, wh mit him to keep the star accurately at the intersectio illuminated cross-wires. The driving of the clock is rate that this is accomplished almost automatically small changes in atmospheric refraction and othe require minute displacements of the instrument to from time to time, to insure the perfect immobilit stellar images upon the photographic plate.

Besides the ten-inch camera and the guiding t the Bruce telescope carries three other cameras, wit of 6 inches, 3.4 inches, and 1.6 inches aperture resp Thus four photographs of the same part of the hea different scales, determined by the focal lengths lenses, are obtained in a single operation. Our kn of the structure of the vast girdle of stars that fo Milky Way is derived in very large part from a photographs made with such an instrument. At t Observatory Barnard used the six-inch Willard lens advantage in photographing these star clouds, and through the opportunity afforded by the Hooker Ex at the lower latitude of Mount Wilson, he has car work farther south of the celestial equator. The Br scope, temporarily transferred from the Yerkes Obser

Mount Wilson for use during th
has yielded some remarkably fi
The smallest of the four photo
tion is taken with an ordinary
inches aperture and 6.4 inches
a region about fifteen degrees[1]
about 1.7 inches in diameter
With the ten-inch lens the fiel
limited to about eight degrees
to include extensive star clou
scale, due to the greater focal
brings out details of structur
smaller photographs. Plates V
originals in the same proportio
of the photographs made with

The Milky Way, as revea
a most extraordinary spectacl
compose it are grouped in ev
intertwined with long reache
Here and there vacant regions
than the background of the
extending through the entire t
perhaps lead one to suspect th
be cutting off the light from
Again, a nebula of great extent,
bounded on the other, may su
yond our present means of in
spread by certain nebulae seen
though in most cases we cann
the stars are actually within th
in the line of vision. The sure
stars and surrounding nebulae i

[1] Readers who are not accustomed to
the two "pointers" of the "Dipper" are a

as will be shown in a subsequent chapter. It has been f that stars of different spectral types, which are ordin assumed to indicate different degrees of development not equally represented in the Milky Way. The conne between these stars and surrounding nebulae, and the pos relationship between spectral type and the grouping o stars in the cloudlike forms of the Galaxy, is one o important problems of the present time. Our knowled the Milky Way and its structure is still very meager, bu future is certain to bring great advances.

These illustrations may suffice to show the uses o ordinary camera lens in investigations bearing upon general structure of the Milky Way. A simple com son will serve to bring out both the advantages and advantages of large telescopes in studies of a similar Plate X shows the Milky Way in *Ophiucus* from one of nard's photographs made with a portrait lens. It affo superb picture of this part of the sky, such as no v observations with any telescope could supply. If the region of the heavens were examined with a large teles the field of view would be so restricted that no p impression could be obtained as to the character of Milky Way or the distribution of the stars within it would, of course, be possible to count one by one the dreds of stars included within a single field of view, an long and laborious measurements to map these stars ultimately to build up, from combination into a single pi of the results thus obtained, a representation of the M Way. However, such a task would occupy years of l and the result would be less valuable, for many purp than that illustrated in Plate X. This picture is an graphic record, showing not only the distribution of stars, but also their relative brightness on the date of exposure.

Since such results are
value of large telescope
means. Plate XI is a r
cluster *Messier* 11, whic
small circular white dot
The short focal length of
form upon the plate a s
region in the heavens, is
single stars of this cluste
Plate XI was made by
telescope, which has a foc
pared with the focal leng
used for Barnard's photo
obtained with the Yerke
times as great as in th
great scale, while disadv
the question of the gen
would be in the highest d
under consideration invol
in the cluster *Messier* 11
are so close together upon
are confused. With the
widely separated from on
and the brightness of eac
precision. The Bruce le
Plate IX had been enlarg
XI, this cluster would b
Messier 13 (Plate XIX)
Bruce lens.

It may be of interest t
illustrative of the advanta
classes of work. Plate X
Moon, made by Ritchey
scope, which is eighteen

excellent general idea of the lunar topography. But if the detailed structure of the lunar mountains is to be investigated, such a picture as that reproduced in Plate XIII would evidently be far more effective for the purpose. *Theophilus*, the great ring mountain here represented, may be seen in Plate XII on a smaller scale. The large-scale picture was obtained by Ritchey with the forty-inch telescope, which, as already remarked, has a focal length of sixty-four feet. The scale of the original photograph was therefore about three and one-half times as great as that of the photograph taken with the Kenwood telescope. In consequence of the larger scale of the Yerkes picture, it brings out many small details which are entirely lacking on the Kenwood photograph.

These illustrations of the separating power of the large telescope may lead us to an examination of the instrument itself (Plate XIV). Although so much larger, it differs in no essential particulars from the Bruce photographic telescope, also made by the firm of Warner & Swasey. The great weight of the forty-inch lens, amounting with its cell to half a ton, requires that the tube which carries it shall be of immense rigidity and strength. This tube, sixty-four feet in length, is supported at its middle point by the declination axis, which in its turn is carried by the polar axis, adjusted to accurate parallelism with the axis of the Earth. By means of driving mechanism in the upper section of the iron column, the whole instrument is turned about this polar axis at such a rate that it would complete one revolution in twenty-four hours. Although the moving parts weigh over twenty tons, the telescope can be directed to any part of the sky by hand, but this operation is much facilitated by the use of electric motors provided for the purpose. When once directed toward the object to be observed, it will frequently happen that the lower end of the telescope is far out of reach above the observer's head. For this reason the

entire floor of the observi
eter, is constructed like ar
a lever, can be made to
twenty-three feet. Thus
rendered accessible even
(Plate XV). In order
rected to any part of the sl
(Plate XVI), is mounted
desired position by mea
from the rising-floor.

The telescope is used
conjunction with appropri
to the lower end of the t
is formed. We have alre
cluster taken with this te
process of making it. A
object-glass was designe
maker, the late Alvan G.
be employed for photogr
distinguishing features o
may be said that the forr
as to unite into an image
yellow and the green, t
With the only varieties
pieces, it is impossible t
image all of the red, the
violet rays that reach us
optician decides to produ
observations, he delibera
rays, simply because the
the yellow and green rays
star produced by a large
rounded by a blue halo,
the optician. These very

the ordinary photographic plate is most sensitive; hence in a photographic telescope the blue and violet rays are united, while the yellow and green rays are discarded.

The forty-inch telescope is of the first type, constructed primarily for visual observations. In order to adapt it for photography, Ritchey, then a member of the Yerkes Observatory staff, simply placed before the (isochromatic) plate a thin screen of yellow glass, which cuts out the blue rays, but allows the yellow and green rays to pass. As isochromatic plates are sensitive to yellow and green light, there is no difficulty in securing an image with the rays which the object-glass unites into a perfect image. During the entire time of the exposure some star lying just outside the region to be photographed is observed through an eye-piece magnifying 1,000 diameters. This eye-piece is attached to the frame which carries the photographic plate, and is susceptible of motion in two directions at right angles to one another (Plate XVII). In the center of the eye-piece are two very fine cross-lines of spider web, illuminated by a small incandescent lamp. If the observer notices that through some slight irregularity in the motion of the telescope, or some change of refraction in the Earth's atmosphere, the star image is moving away from the point of intersection of the cross-lines, he instantly brings it back by one or both of the screws. As the plate moves with the eye-piece, it is evident that this method furnishes a means of keeping the star images exactly at the same position on the plate throughout the entire exposure.

Many other comparisons of large and small telescopes might be given, and some of these will be included in subsequent chapters. They all serve to demonstrate that each telescope has advantages and disadvantages peculiar to its size and type of construction. For some purposes small camera lenses are to be preferred to all other instruments.

In fact, without their aid
importance could never h
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while refracting telescop
excellent results. These
limitations, and must yie
other kinds of work. T
brought out in the next

CHAPTER VI

DEVELOPMENT OF THE REFLECTING TELESCOPE

On a night in April, 1845, while sweeping the sky in the constellation of the *Hunting Dogs*, the observers with the great Parsonstown reflector discovered a spiral nebula. The instrument with which the discovery was made may well be regarded as one of the most remarkable scientific achievements of the nineteenth century. With its immense mirror, six feet in diameter, having a focal length of fifty-four feet, the great telescope of Lord Rosse surpassed in size all others ever constructed. Unfortunately for the progress of science, the engineering methods of that day were inadequate to provide a suitable mounting for this gigantic instrument. All parts of the machinery had to be constructed on the spot, with such tools as the period and the circumstances afforded. It is no small credit to the Earl of Rosse that under these conditions the telescope was ever erected, and kept in active use by an able company of observers. Supported upon a ball-and-socket joint at its lower end, the enormous tube, swung in chains, was confined to observations within a short distance of the meridian by two flanking stone walls. The observer, mounted upon a platform far above the ground, saw the image of an object as he looked down into the tube. To the present-day astronomer, provided with every appliance to facilitate the finding of an object, and with an accurate driving-clock which moves the telescope so steadily and uniformly as to maintain the image in the field of view for hours together, it is little short of marvelous that the observers with the great Parsonstown reflector were able to obtain results of value. But, in spite of the difficulties to be over-

come, both in manipul
opportunities for obser
Ireland, Lord Rosse an
uable discoveries in thei
that of the spiral nebu
the most significant of t
fore this chapter is conc
object, which once stoo
as the only visible repre
has now come to be rega
a type of the most inter
of nebulae.

The history of the P
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methods, these imperfec
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impossible. But the em
has imposed a new condi
the constructors of telesc
satisfactory photographs
optical qualities of the
fects as atmospheric distu
that the mirrors be so r
moved by the driving-c
depart, during exposure
one-thousandth of an i
photographic plate.

In view of the difficulties to be overcome, it will be understood that to accomplish such a result is no small task. In the first place, the mirror, which is so sensitive to deformation that it will bend under its own weight unless supported by special apparatus, must be firmly mounted, yet without strain, at the lower end of an open tube. In the second place, protection must be provided against currents of warm and cold air, and even against the heat radiated from the observer's body, on account of the great sensitiveness of the mirror to heat, and of the light-rays to irregular refraction in the telescope tube. These precautions having been taken, the tube must be so mounted that it can be moved with perfect steadiness and uniformity about an axis parallel to the axis of the Earth. This condition is imposed by the necessity of counteracting the apparent motion of the star through the heavens, due to the rotation of the Earth. But while this rotation is uniform, the motion of the star is not, since the displacement of its apparent position from its true position in the heavens, due to the bending of its rays during transmission through the Earth's atmosphere, varies with the height of the star above the horizon. It therefore becomes necessary, as previously explained, to supplement the uniform motion of the driving-clock by corrections, accomplished by the hands of an observer. All these obstacles having been surmounted, there still remain serious sources of difficulty in the shaking of the telescope by the wind, the changes of temperature during the exposure, which alter the focal length of the mirror, and finally, most serious of all, disturbances in the atmosphere which tend to blur and confuse the image, instead of leaving it, sharp and well defined, to make its record upon the photographic plate. It should also be remembered that the observer must be prepared to hold his eye at the eye-piece, and correct every few seconds the position of the plate, throughout exposures lasting several hours,

in an open dome where t
be below zero.

After the erection o
attention of opticians was
of refracting telescopes,
apertures of fifteen inch
thirty-six inches in the L
in the Yerkes refractor (
ful attention was given t
tion, and the Lick and Y
successful products of m

The development of t
mainly to amateurs, whe
professional opticians and
To the inadequate equip
therefore be ascribed ma
ings of reflecting telesc
flectors of large aperture,
opticians and engineers
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attention was paid to t
mirrors, which causes t
treatment than is amply
a lens.

In stellar spectroscop
with reflectors by Hugg
early period, but it was
teenth century that such
considerable degree of suc
The first photograph of a
ing telescope by Draper
Nebula in *Andromeda*,
twenty-inch reflector, sh
spiral form of this rem

some of the great possibilities of investigating nebular structure with instruments of this type. Briefly speaking, their superiority to refractors lies in the fact that the light is not weakened by passage through glass, but, after reflection from a surface of pure silver, all the rays, independently of their color, are united in a common focus. With a refractor many of the rays are completely cut off during transmission through the glass of the lens, which is as impervious as so much steel to the very short waves of the ultra-violet spectrum. Furthermore, a lens does not unite all the rays of different colors into a single focus, but forms a series of images, corresponding to light of different wave-lengths. In order to get a sharp photograph with a refracting telescope, it is therefore necessary to discard some of these rays, in the manner already described (p. 35). The reflector, on the contrary, utilizes all of the light[1]—an advantage which is clearly shown by the results obtained with this type of telescope.

The photographic studies of nebulae made by Keeler with the Crossley reflector of the Lick Observatory, mark a step of the greatest importance in the development of the reflecting telescope. The mounting of this instrument, constructed in England some years previously, and presented to the Lick Observatory by Mr. Crossley, was very poorly adapted to carry the excellent mirror of three feet aperture. But through the extraordinary efforts of Keeler, whose severe exertions in carrying out this work hastened his death, the mounting was so strengthened and improved as to permit remarkable results to be obtained. In other hands, even after these improvements had been made, it is doubtful whether such exquisite photographs would have resulted. But, after many unsuccessful efforts, Keeler learned how to overcome the difficulties peculiar to the instrument, and in this he has been

[1] Except a certain percentage lost in reflection.

ably followed by Perrine
refer to their results.

The mounting of the
Yerkes Observatory was
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for the exacting requirem
inches in diameter and
structed by Ritchey in 1
mirror is of the highest
optical tests that can be
telescope, designed by
Ritchey, was constructed
Observatory, and is very
(Plate XVIII) the mirror
end of the skeleton tube.
a small plane mirror, so
angle of 45° with the a
therefore of the Newtoni
the photographic plate n
reflection of the cone of
double slide plate-carrier
in size, is precisely simil
the forty-inch refractor (

A comparison of the re
with those secured with
suffice to show the pecu
certain kinds of work.
forty-inch refractor has
work that could not be
the two-foot reflector.[2]

[1] A new and satisfactory moun
reflector.

[2] For example, the scale of the
of the two-foot reflector. Moreove
for which the latter cannot be use

stars, particularly in the photography of nebulae, the two-foot reflector is especially useful. It is possible with this instrument, in an exposure of only forty minutes, to photograph stars which are at the extreme limit of vision with the forty-inch refractor. With longer exposures, countless stars, which can never be seen or photographed with the large refractor, are recorded on the plates. Compare, for example, the photographs of the star cluster *Messier* 13, reproduced in Plates XIX and XX. The principal advantage of the reflector in such work, as already explained, is the concentration of the light-rays, irrespective of their color, in a single focal image.

The photographs of nebulae obtained by Ritchey with the two-foot reflector show in a remarkable way the beauty and delicacy of structure which characterize these objects. It will be seen from the illustrations in the plates that the nebulae are of many types, although the spiral form predominates. The Great Nebula in *Orion* (Plate XXI), which is the most brilliant of the larger nebulae, is of irregular form, and marked complexity of structure. Of very different pattern is the beautiful nebula in *Cygnus*, the delicate filamentous structure of which is admirably shown by Ritchey's photograph (Plate LXXXVII). In the nebulae which envelop the stars of the *Pleiades* (Plate LXXXVI) two very different types of structure are shown; long parallel filaments predominate, but there may also be seen in the photograph a mass of nebulosity resembling the flame of a torch blown by the wind. But although, as we shall see, evidences may be found of the relationship of the stars in these nebulae to the cloud-forms themselves, the spiral nebulae certainly appeal most strongly to the imagination. The largest of these, the Great Nebula in *Andromeda*, is perhaps the most interesting object in the heavens (Frontispiece). Persistent attempts to measure the distance of this nebula from the Earth, made with the most

powerful of modern inst
may therefore conclude
ceivably great, and tha
nebula are so enormous
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spiral character of this ob
graph, although beyond
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of photographs made ma
motion has been detected
what we already know f
nebula is exceedingly re
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powerful instrumental m
intervals of time must se
be compared.

The Great Nebula i
largest representative of
was first made known thr
spiral nebula in the *Hun*
photographs we are fortu
spiral nebulae, which di
all cases show clearly th
and XC). As already st
gations with the Crossley
objects of this kind are co
over with an immense nu
gation of these nebulae,
of the future, should
importance.

CHAPTER VII

ELEMENTARY PRINCIPLES OF SPECTRUM ANALYS

THE problem of determining the nature of the neb seemed to be placed beyond solution by telescopic m when it was found that star clusters exist in which the star so densely packed that they cannot be separately distingui by any telescope. A photographic illustration of this is g in Plate XIX. In Plate XI we see a cluster easily resc into its constituent stars. In the case of *Messier* 13, how the photograph here reproduced might leave some doub the score of resolvability.[1] Visual observations, better petent than photographic ones to settle this particular p remove the doubt in the present instance. But other clu are still more closely crowded, and it was easy to believe the unresolved nebulae might be objects of this nature. structure of such a nebula as that shown in Plate XC m also be supposed to favor such a view. Sir William Hers great not only as an observer, but as a philosopher who lo deep into the nature of things, was not deceived by t circumstances, and persisted in his belief that the neb are masses of uncondensed gas, differing essentially clusters of stars. As evidence of the uncertainty w nevertheless existed, it must be added that Sir John Hers though himself a great philosopher, was led to a conf conclusion. For him no nebula existed that could nc resolved with a sufficiently powerful telescope into a cong of stars. Under these circumstances it is evident that additional means of analysis must be called upon to solv problem. For as telescopes increased in size the neb remained unresolved, showing that either they were in

[1] Even the large-scale photograph in Plate XX does not separate the closest

nature unresolvable, or
would be required to re

This was the condit
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found in later years to
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found, indeed, that the
in the light of the plan
in the spectra of some
cluded that the cause

Earth's atmosphere, he nevertheless failed to discover
true explanation, and thus did not perceive the pos
ties of the science of spectrum analysis.

Let us consider for a moment what happens when
is passed through a prism. We may assume the light
derived from the glowing filament of an incandescent
placed just in front of a narrow slit. After passing thr
the slit a (Fig. 1) the divergent rays fall upon the le

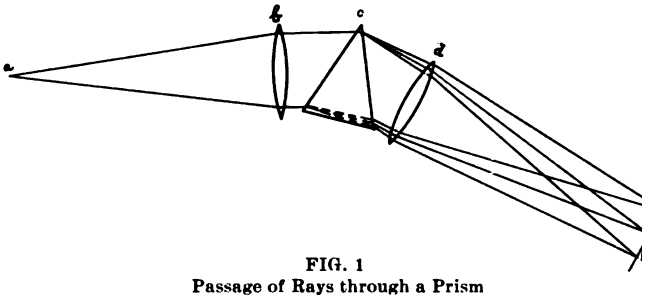

FIG. 1
Passage of Rays through a Prism

which renders them parallel, and is known as the collim
lens. The parallel rays now meet the face of the pri
through which they are transmitted. After passing thr
the prism the rays fall upon the lens d, precisely simil
the collimating lens, which forms an image on the scre

Now, when light strikes a prism it is deviated fr
straight path, and the amount of its deviation depends
the color of the light. Yellow light, for example, is defl
by a prism more than red light. Green light is defl
more than yellow light, blue light suffers even a gr
change of direction, while violet light is deflected most
It is thus evident that if the light from the incande
lamp were pure red, and contained no other color, we sl
have a red image of the slit at R. If it were yellow, a y
image of the slit would be formed at Y. Green light
form a green image of the slit at G, blue light a blue i

at *B*, and violet light a
compounded of all these
ate gradation of tint. W
therefore dispersed into
red at one end through yel
is called a *continuous* sp
light from any white-hot
Liquids, or even gases
give a continuous spectru
and gases, under ordinar
spectra of bright lines, b

For example, let us re
by a non-luminous gas fl
is burned after being th
introduce into this flam
instantly colored a deep
transmission through th
upon the screen a single
powerful instrument woul
very close together on th
poses we may consider
metal sodium, which in c
common salt. Wherever
whether in a flame, or be
tric arc, or in the atmosp
most distant star, it gives
at precisely the same p
ciently powerful instrum
its presence, when accu
prove the existence of sod
Plate XXII).

Most substances, when
in this way, produce mo
slit upon the screen. Th

the flame, gives two red lines and a strong blue line. F
sium gives a line in the extreme red and another i
extreme violet. But the essential point to notice is th
two substances give lines at precisely the same place i
spectrum. From this we may conclude that the spectr
entirely characteristic of the various elements, and ther
that the presence of these elements in a state of vapo
always be recognized by the detection of their peculiar

The spectra of the elements are of all degrees of
plexity, ranging from only two or three lines up to se
thousand. Iron, for example, when turned into vap
the electric arc, shows, after analysis by the prism, se
thousand lines, irregularly distributed through all
of the spectrum (a few of these are shown in Fig. 2,
XXII). It is evident, therefore, if the lines are to be cl
distinguished from one another, and so accurately recog
as to avoid confusing a line of iron, for example, witl
belonging to some other substance, that powerful dispe
may be necessary; i. e., the various lines must be sepa
from one another as far as possible by drawing out the
trum to a great length. This can be done by passin
light through several prisms in succession, rather
through a single prism, as in the present instance.

So far we have referred to the spectra of metallic va
rendered luminous in the gas flame or in the electric
In order to obtain the characteristic spectrum of a gas,
as hydrogen, it may be placed in a tube, and made
nous by an electric discharge. The best results ar
tained after the pressure in the tube has been reduce
pumping out some of the gas, until the electric disc
passes quietly and continuously, so that the whole in
of the tube continues to glow with the light of its gaseous
tents. This light, when analyzed by a spectroscope like
shown in Fig. 2, is found to give lines which are char

istic of the gas employed. The light of hydrogen in a vacuum tube, for example, gives precisely the same spectrum as the light of hydrogen proceeding from one of the great flames at the edge of the Sun.

We have now considered two types of spectra: (1) the *continuous* spectrum, produced when a solid body, a liquid, or

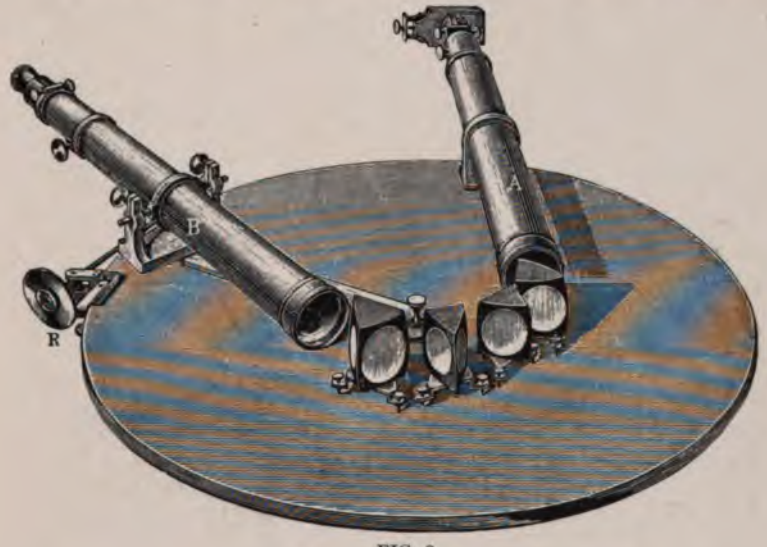

FIG. 2
Kirchhoff's Spectroscope

a highly compressed gas, is rendered white-hot by sufficient heat; and (2) a *bright-line spectrum*, consisting of bright lines, irregularly distributed on a dark background, and derived from the prismatic analysis of the light emitted by luminous metallic vapors, or gases rendered incandescent by electric discharges. One other type of spectrum remains to be mentioned: a *dark-line spectrum*, such as Kirchhoff observed and explained when he effected his famous analysis of sunlight at Heidelberg in 1859.

We have already remarked that Fraunhofer had noted

the existence of dark lines in the continuous spectrum c
Sun, and accurately measured their positions, though
out understanding their meaning. Kirchhoff, using the
prism spectroscope shown in Fig. 2, saw these same
lines in the solar spectrum, and succeeded in explaining
origin. In the yellow part of the spectrum he observe
strong dark lines, very close together. When the sun
was excluded from the spectroscope, and a gas flame cor
ing sodium vapor was placed in front of the slit, two s
bright lines, occupying exactly the same positions a
dark lines of the solar spectrum, were seen in their
The flame was then copiously charged with sodium
and retained in its position in front of the slit, the sun
being permitted to shine through it. It was immedi
noticed that the two dark lines in the solar spectrum
considerably darker and more conspicuous when the sun
passed through the sodium flame than when it was obs
alone. Furthermore, it was found that when any white
producing a continuous spectrum without lines, was all
to shine through a flame containing sodium vapor, the
of the flame was to produce two dark lines in the yello
the precise position of this conspicuous pair of dark lin

Iron, when transformed to luminous vapor in the el
arc, gave an even more convincing proof that the true e
nation of the solar spectrum had been found: the b
lines observed in its spectrum by Kirchhoff and Bu
were seen to be represented in the solar spectrum b
equal number of dark lines, precisely resembling them
in position and in relative intensity. Magnesium, n
calcium, and other substances gave similar results, an
conclusion was irresistible that all of these substances
in the Sun in a state of vapor. It followed from these e
iments that the body of the Sun must be an intensel
mass, emitting white light, which, if it could be obs

alone, would give a conti
of any kind. Surroundi
observations proved the e
taining, in a state of vap
Earth. These vapors, th
of the Sun, are neverthel
undoubtedly exceeding th
Hence, if their light coul
seen to give a very comple
all of the lines characteri
be present. It will be sh
bright lines may be see
apparatus is so adjusted
chromosphere to the slit
all of the light from the
this spectrum are less bri
due to the more highly
when observed against
dark by comparison.
shown by Kirchhoff's exp
the same rays which the
radiations, emitted by t
dark lines of the solar sp
that these so-called dark
since it will be explained
can be taken by the light
troheliograph, showing t
element in the solar atm

It immediately becam
that the method of analys
immensely powerful in e
Huggins, Secchi, and Ru

[1] In Fig. 1, Plate XXII, the tw
the center of the arc. The cooler
absorption, the narrow dark lines

observations on the spectra of stars, and soon establis system of types, based upon the examination of the sp of several thousand objects. This work has since been gr extended through the application of photographic met introduced by Huggins, and applied with marked succe Draper and many others. In 1868 the spectroscope used for the first time to analyze the red flames seen d total eclipses of the Sun. Not only did it demonstrate gaseous nature, but a short time later, through the effo Janssen, Lockyer, and Huggins, it was found possible t ploy the spectroscope to observe the forms of the promin in full sunlight.

These and other applications of the spectroscope wi more fully described in subsequent chapters. Our pr purpose is to explain how the new method, in the han Huggins (Plate XXIII), finally proved beyond doubt certain nebulae are to be sharply distinguished from clusters.

Sir William Huggins' account of his first spectros examination of a nebula is recorded in the *Publications o Tulse Hill Observatory*, Vol. I:

> On the evening of August 29, 1864, I directed the spectro for the first time to a planetary nebula in *Draco*. I looked in spectroscope. No spectrum such as I had expected! A s bright line only! At first I suspected some displacement o prism and that I was looking at a reflection of the illuminate from one of its faces. This thought was scarcely more momentary; then the true interpretation flashed upon me. light of the nebula was monochromatic, and so, unlike any light I had as yet subjected to prismatic examination, could n extended out to form a complete spectrum. After passing thr the two prisms it remained concentrated into a single bright having a width corresponding to the width of the slit, and oc ing in the instrument a position at that part of the spectru which its light belongs in refrangibility. A little closer lo showed two other bright lines on the side toward the blue, all

lines being separated by int
the nebulae was solved. Th
light itself, read: Not an ag

With this advance a
power of the spectroscope
gas and a starlike mass o
lished it at once in the pl
ment of the student of ste
that the unformed nebula
which stars are made.

It must not be forg
number of nebulae give a
them to be gaseous. M
very numerous spiral typ
which no lines have yet b
certainly formed from t
from the "green" gaseou
tion must be broad enoug

CHAPTER VIII

GRATING SPECTROSCOPES AND THE CHEMICAL COMPOSITION OF THE SUN

THE general process employed by Kirchhoff to in gate the chemical constitution of the Sun has al been described, but it also seems desirable to gi account of the perfected method used for this purp a modern laboratory. In order to prove that a given stance exists in the Sun, its lines must be identified certainty in the solar spectrum. The spectrum of iro example, contains thousands of lines, and it might happen that through chance proximity many of these would appear to coincide with some of the exceed numerous lines of the solar spectrum. It is evident, fore, that the method of comparison adopted must be as to permit of a high degree of precision in measurin positions of the lines. In other words, the dispersion spectroscope must be so great as to give a very long trum, in which the lines are well separated from one an Thus their positions can be accurately determined, and th no danger of confusion in the case of closely adjacent which in a less powerful instrument might be seen as

The recent great advances in spectroscopy have bee in very large measure to the success of Rowland in gratings of high resolving power. In a previous chap was remarked that the dispersion of a spectroscope m increased by increasing the number of prisms through the light passes. This not only gives a longer spectru also increases the resolving power of the instrume its capacity of separating closely adjacent lines.

through the loss of light
becomes very serious w
a limit is soon set to t
prism spectroscopes. It
has played so large a p
the subject. For the re
depends only upon the to
the light efficiency, per
large grating as for a sm

The production of ve
the use of large and accu
land succeeded in accom
at the Johns Hopkins U
sists of a polished metal
tant lines are ruled with
of the spectra given by
number of lines it contai
spacing. The difficulty
ciated when it is remem
from 10,000 to 20,000 li
positions of the lines, an
the interval between the
the grating, tending to
duced by it.

Gratings that gave v
years ago by Rutherfurd
Rowland to surpass then
celebrated ruling-engine
regular use in the under
of the physical laborator
depend for their success
is employed to move th
1/15,000 of an inch bet
mond, contains almost no

that the screw is entirely free from error, but the effe
the exceedingly minute irregularities is almost wholly
pensated by ingenious devices that form a part of the
ing-engine. The machine is automatic in its action,
when set in motion the ruling of a large grating goe
without interruption for six days and nights before
completed.

The gratings manufactured on Rowland's machine
gone into observatories and laboratories in all parts of
world, where they have been the principal agents of spe
scopic research during the last quarter of a century. T
great efficiency has caused them to displace prisms
nearly all spectroscopes in which very high resolving p
is required. As we shall see later, however, the prism
remains of great importance to the spectroscopist, particu
in work requiring moderate resolving power, where it
a much brighter spectrum than a grating.

Rowland's contributions to spectroscopy were by no m
confined to the manufacture and distribution of optical
ings. In addition to his very extensive researches on
solar spectrum, and on the spectra of the elements
invented the concave grating, which now forms an esse
part of the powerful spectroscopes found in many lal
tories. Prior to Rowland's time the comparatively
gratings which had been made were ruled on plane surf
and employed with the ordinary collimator and teles
of the laboratory spectroscope. That is to say, the pris
an ordinary spectroscope was removed, and the grating
stituted for it. In such an instrument the rays of light,
passing through the slit, fall upon the collimator lens, w
renders them parallel. The parallel rays then meet the
face of the grating, where they are diffracted and spread
into a spectrum. This spectrum is observed or photogra
with the aid of a second lens, which forms its image or

retina or on a sensitive p
kind, used with the 40-inc
observations of the Sun,

Rowland showed, fro
if the grating were give
collimator lens, and the
ing telescope as well, mi
entirely dispensed with
also devised the form of
ing for a concave grating
trated in Fig. 3. In the di
a is the slit through whi
light enters, *b* the concav
ing, and *c* the eye or
graphic plate. It will b
that no lenses enter in
construction of the app
for some classes of work
a point of great advanta
the largest gratings used
of the grating-plate, whi
the grating *b* and the ph
spectrum given by such
and a portion of the spe
be recorded by a single
In order to pass from o
the grating-carriage *b* i
causes the plate-carriage
slit on the rail *ac*. The
in a dark room, to whic
which passes through th

It should be remark
produces not merely a si
which can be observed su

along the track away from the slit. The first-order s
trum lies nearest the slit. The second-order spectrum, t
as long as the first, which it partially overlaps, lies fa
from the slit. The third and fourth orders, of increasi
higher dispersion, lie still farther from the slit. Only a
tion of the fifth order can be observed with this instrun
and the higher orders, also beyond reach, are usually
faint to be of any service.

Let us suppose that we wish to determine with su
spectroscope whether iron exists in the Sun. To accom
this, sunlight must be reflected from the mirror of a heli
(driven by clock-work, to maintain the beam in a fixed d
tion) to the slit. Between the slit and the heliostat a le
introduced, for the purpose of forming an image of the
upon the slit. When the illumination is secured in this
the whole grating is filled with light from the diverging
The grating then produces an image of the solar spect
upon the photographic plate, where it may be recorde
giving a suitable exposure.

To facilitate an accurate comparison, the solar spect
is photographed side by side on the same plate with
spectrum of the substance whose presence in the Sun
be determined. In order to accomplish this, one-half o
slit is covered, and the sunlight is admitted through
other half. Thus the solar spectrum is photographe
one side of the plate. After this exposure is completed,
sunlight is shut off, and the screen in front of the slit m
so as to cover the half previously open, and to uncover
other half. The image of the Sun on the slit of the spe
scope is then replaced by an image of an electric arc li
burning between two poles of iron. The spectrum of the
vapor is thus produced on the plate, and a strip of
spectrum is photographed beside the strip of solar spect
This is illustrated in Fig. 2, Plate XXII, where the u

strip is a small part of t
by a glance at this photo
are represented in the so
lines, which accurately m
work on the solar spectr
correspond with iron lin

The same process can
ence of other substances
the electric discharge n
metallic rods, or fragme
hole drilled in one of the
lamp. In the latter case
the impurities which the
appear on the plate with
tion. But these extra l
usually give no trouble
lines, however, is not alw
Many substances are do
only a small number o
difficult to decide wheth
sufficient to warrant on
The matter is usually d
certain well-known grou
are considered to be esp
are actually represented
apparent coincidence wi
belonging to the same
suspicion. In the case
by the aid of vacuum tu
pressure, is illuminated
lines given by a hydroge
shown to coincide in posi
in the Sun.

After many years of s

methods, Rowland reached the conclusion that the chen composition of the Sun closely resembles that of the E Certain elements, such as gold and radium, iodine, sulp and phosphorus, chlorine and nitrogen, have not detected in the Sun. But this does not prove that they certainly absent, as their level in the solar atmosphere the low degree of their absorptive effects might pre them from being represented. On the other hand, var substances, not yet found on the Earth, are shown by n unidentified lines of the solar spectrum to be present in Sun. Some, if not all, of these, will probably be discov by chemists, just as helium was found by Ramsay in cle (p. 78). Rowland remarked that if the Earth were he to a sufficiently high temperature, it would give a spect closely resembling that of the Sun.

The most perfect maps of the solar spectrum are thos Rowland and Higgs. These are enlarged from photogr made with the concave grating, and contain an imm number of lines. Both maps extend into the extreme u violet spectrum (the invisible region beyond the violet), that of Higgs includes a considerable region of the infra (also invisible to the eye) where photographic plates s tized for red light with alizarin blue or other dyes mus employed. Both maps are provided with scales of w length, so that the approximate positions of the lines be read off at once. The precise positions of all solar photographed by Rowland are given in his *Prelimi Table of Solar Spectrum Wave-Lengths*, which record places of about 20,000 lines. This table, although kn to contain some small errors, is at present employed b spectroscopists as the standard of reference. It gives I land's identifications of the solar lines, but about thirds of the lines have not yet been referred to any kn element. Recent investigations of the spectra of var

metals will no doubt perm
lines to be identified.

In any examination o
cannot fail to be struck b
lines in certain regions.
for example, near the w
most casual examination
the intensity of the cou
conspicuous here. How
in Plate XXV, which is a
of this part of the spectru
The lines which thus cha
lines, since they are due
the Earth's atmosphere.
XXV contains a large nu
Since the amount of wate
it is natural that the inte
accordingly.

All of the telluric li
spectrum of the Sun when
case the light traverses a
before it reaches the s
spectrum of the high a
expected to show marked
telluric lines. This is a
therefore affords one mea
absorption of our atmosp
duces two similar groups
designation of the solar
end of the solar spectru
groups in the spectrum o
the Eiffel Tower, as seen
Paris, at a distance of ab

An ingenious method

guish the telluric lines from those due to absorption i
Sun's atmosphere. According to Doppler's principle
lines in the spectrum of the east limb of the Sun mu
displaced toward the violet (by motion of approach),
those from the west limb toward the red (recession), sinc
Sun is rotating on its axis in a period of about twent
days. It occurred to Cornu that this fact might give a
delicate means of picking out the telluric lines, since onl
lines of solar origin can be displaced by the Sun's rot
while those due to absorption in the Earth's atmos
remain in their normal positions. He formed a small i
of the Sun on the slit of his spectroscope, by means of a
which could be made to oscillate rapidly, thus causing th
limb and the west limb of the Sun's image to fall altern
upon the slit. If the spectrum is observed while the i
is oscillating, the lines of solar origin will be seen to
rapidly to and fro through a short distance, while the te
lines will remain fixed. This method was successfull
ployed by Cornu in an important study of the telluric
Other investigations of these lines, which have result
the production of extensive maps, have been made by Th
(continued by Spée), Becker, and McClean. In these i
tigations the telluric lines were distinguished by observa
of the spectrum of the high and low Sun.

If passage of sunlight through our atmosphere is
competent to produce dark lines in the solar spectrum,
evident that the sunlight reflected from a planet should
evidence of its double transmission through the pl
atmosphere. This method is actually employed to deter
the presence and the composition of the atmospheres o
planets.

Remarkable as was Rowland's success in the manufa
of gratings, and the measurement of wave-lengths with
aid, it has recently been surpassed by Michelson. Wit

interferometer, an instru
has established the length
national Bureau of Weigh
waves. This fixes, with
length of certain lines in t
wave-lengths were adopte
the International Union f
as primary standards, o
lengths, to replace Rowlan
his invention of the eche
form of grating, composed
equal in thickness, piled c
through which a parallel
spectra thus produced ar
resolving power surpasses
The echelon spectroscope
ing compound lines, the
gether that they cannot b

The latest success achi
up still greater possibilit
can be used only for the s
lines; its application is t
problems. For more ge
and in the solar observa
resolving power, are requ
a disk of speculum metal
fully made by Rowland
Michelson has completed
perfect screw, on which h
inch gratings. He hopes
largest for which his mac
to believe that his plan
with four screws, which sl
its amount in a single s

production of good 20-inch gratings. The enormous i
tance of such gratings, in their application to the study
Sun, will become clearer as we proceed. One difficu
be overcome will be recognized when it is remembere
a 20-inch grating, having 12,500 lines to the inch,
contain more than 2,000,000 lines, each about 10 inches
The microscopic diamond crystal, used to cut all these
in the hard surface of the speculum metal, must not bre
change its form appreciably, during the entire period
work.

It is satisfactory to add that Jewell has recently
structed a new ruling machine at the Johns Hopkins U
sity which appears likely, from preliminary tests, to be
rior to Rowland's. We thus have good reason to hop
the best existing photographs of the solar spectrum wil
be surpassed.

CH

PHENOMENA O

THE results described light of the Sun as a whc face phenomena. In mc scribed similar results m removed to the distance c would no longer be poss telescope, to detect an ap would be reduced to a m however, to afford sufficie tion. But it has already of the Sun acquire thei comparative proximity of stars are so far away tha tween the radiations char disks. The spectroscopi observe in such cases a cc superposition of the spect ena. The Sun, on the c image at the focus of a p eter as great as 7 inches the light from any point small area of the solar su extensive knowledge of t derived from an examina upon this fact.

The appearance of the Plate II, which is a rep

[1] The actual diameter of the S

The Sun's light is too brilliant to permit of visual obs tion without some method of reducing its intensity. Th means of accomplishing this is by the aid of the pola helioscope, which is attached just in front of the piece of the telescope. The cone of light from the o glass meets a plane surface in the helioscope, from wh is reflected at an angle such as to polarize the rays. well known, the amount of plane polarized light whic be reflected from a second surface depends upon the at which the rays meet this surface. Consequentl rotating the reflecting prism the amount of light reaches the eye can be varied at will, thus produci image of any desired brightness. When protected b device, the eye of the observer of solar phenomena is jected to even less strain than is frequently experienc work on fainter objects.

A casual glance at the solar image is sufficient to that it is much darker near the circumference than at th tral part of the disk. This falling-off in brightness t the limb is probably due to the absorption of a smok envelope, which completely incloses the Sun. The ab tion is so marked that near the circumference of the Sur about 13 per cent. of the violet rays escape. For the green, and yellow rays the percentage of transmitted increases progressively, until it amounts to about 30 per for the red. It has therefore been concluded that, i absorbing atmosphere were removed, the color of the would appear blue, since the intensity of the violet would be about two and one-half times as great as at pr while the red rays would be only about half again as b as they are now.

The visible phenomena of the Sun's disk include the spots and the faculae. The general appearance of sun- when seen with a low magnifying power, is shown in Pla

Under perfect atmospheri
observed with a powerf
resemble Plate XXVI, w
made by Langley. The
drawing is one of the n
structure yet obtained.
constitute the penumbra
central region, called the
that the darkness of the u
alone, and not in contrast
ings of the photosphere,
surpassing that of the mo
be evident. Knowledge
ficient to set at rest t
merely rents in a brilliant
which a dark and cool int

According to Langley
together, constitute the
on the solar surface. He
stalks of a wheat-field, se
tosphere, and revealing n
the penumbra, where th
toward the central part o
we are observing columns
Sun's interior, the seats o
to the surface the immen
Sun into space. Separ
darker regions, character

Such minute details ca
difficulty. Under ordina
image is not seen as a sh
details are continually b
heated currents in our a
conditions the moments o

the greatest patience and perseverance are required o
part of an observer who would record his impressions o
solar structure. At the best, drawings based upon v
observations must be unsatisfactory, since even the sk
hands of Langley could not secure the perfect prec
which is so desirable. It accordingly might be hoped
here, as in other departments of solar research, photogr
would afford the necessary means of securing results
tainable by the eye. Unfortunately, however, this hop
been only partially realized, as a brief consideration o
best results in this field will show.

It is a comparatively simple matter to make a d
photograph of the Sun. It is only necessary to form a
image, considerably enlarged, upon a "slow" photogr
plate, and then to give an excessively short exposur
means of a shutter containing a narrow slit, which is
across just in front of the plate at very high speed. The
from any part of the Sun reaches the plate only durin
brief interval in which the slit is passing the correspon
part of the image. The exposure for any point may
amount to no more than $\frac{1}{1000000}$ of a second. The pl
graph reproduced in Plate II was taken in this way.

In order to obtain photographs showing the sm
details of the photosphere, it is desirable to use a
image enlarged to a diameter of from 15 to 30 inches,
photographic plates particularly adapted for this class of v
The best direct photographs hitherto made are those t
by Janssen at the Observatory of Meudon, near Paris
portion of one of these pictures, representing the great
spot of June 22, 1885, is reproduced in Plate XXVII.
penumbra is not very well shown, since the exposure req
for the brighter regions of the surrounding photosphe
too short to bring out its fainter details. Even with suffi
exposure, however, such photographs do not reveal the

delicate details recorded
do show, with considera
the photosphere, as Plat
seen, autographically re
which Langley believed
ments reaching down to
sen holds a different vie
to be small spherical ma
vacant regions. In cha
of recent investigations
bear out Langley's view

There can be little d
Sun, showing smaller d
will ultimately be obtai
been secured with a sma
where the conditions ar
of this character. It is
more powerful apparatu
the results would be stil

In spite of long stu
uncertain whether sun-s
as elevated regions of t
supposed, mainly as th
Wilson, of Glasgow, in t
were saucer-shaped cavi
sloping edge of the sa
More recent investigati
Wilson's observations, t
the umbra lies below the
round spots. Faculae
sphere, and the question
umbra is above or below
outside of the faculae.

The only other phe

of the Sun are the faculae. They are usually most numer in the vicinity of Sun-spots, and near the Sun's limb t are sometimes very conspicuous brilliant objects, cover large areas. Near the center of the Sun, however, t are practically invisible, though faint traces of them sometimes be made out on photographs taken with a suit exposure. This increase of brightness toward the Sun's l is assumed to be due to the elevation of the faculae above photospheric level, and their escape from a considerable of that absorption which so materially reduces the bright of the photosphere. Rising above the denser part of absorbing veil, and thus suffering but little diminutio light, they appear near the Sun's limb as bright obj on a less luminous background.

Janssen's photographs tend to bear out the assump that the faculae resemble the rest of the photosphere, dif ing mainly in their greater altitude. They are shown these photographs to be resolved into granular elem similar to those that constitute the photosphere. It will seen later, however, that the faculae play a very impor rôle, since they are the regions from which immense masse vapors rise to the solar surface. These vapors are invis to the eye, and no trace of them is shown on photogra taken in the manner described above. But they may photographed with the spectroheliograph, by the met explained in chap. xi.

THE SU

THE first observation
to an early period. O
dark body of the Moo
sunlight which at othe
and reveals phenomena
well known that, if our
be no such scattering o
as dark during the day
a case the stars would
corona. Formerly, whe
brilliant illumination
knowledge of celestial
of the Sun was of nec
The solar corona was t
flames, or prominences,
Sun's surface.

The corona still rem
no means has yet been
eclipse. Our knowled
observations made duri
Moon shields our atmos
light. The general a
the eclipse of May 2
reproduced from a p
Ritchey. It may be
of light, extending out
face of the photosphe
miles, and exceeded i

parts, by the full Moon. In many ways its streamers semble those of the aurora borealis, and it is indeed poss that their origin may be ascribed to some similar electi cause. During the few minutes of a total eclipse they not seen to undergo change of form, but the outline of corona does vary greatly from year to year, in sympa with the general variation of the solar activity describe another chapter. At times of minimum sun-spots the for the corona resembles that shown in Plate IV. This minin type is marked by great winglike extensions along the s equator, and by much shorter streamers, diverging like near the Sun's pole. At times of maximum sun-spots corona is much more extensive in the polar regions, streamers equaling in length those of the equatorial zon

Spectroscopic observations have shown that the corona sists mainly of gases unknown to the chemist. That i say, the lines in its spectrum do not coincide in position the lines of any terrestrial element. Whether these ga which are probably very light, will ultimately be found the Earth cannot be predicted. Like helium, first know the Sun, they may eventually be encountered, in mi quantities, in some mineral, where they have hitherto esca the chemist's analysis. The fact that the lower part of corona gives a continuous spectrum, with a feeble solar s trum superposed upon it, indicates that minute incandes particles are present, which are hot enough to radiate w light, and which scatter enough sunlight to account for presence of the solar spectrum.

It may now be of interest to explain how the solar cor is photographed during a total eclipse of the Sun, especi as the same means are employed during eclipses in ph graphing the solar prominences, and also because we s have occasion in a subsequent chapter to refer more length to the general type of telescope here represented.

It has already been ex
the Sun given by a telesc
length of the lens employ
as possible the more min
therefore desirable to ob
with a telescope of great
instrument as the 40-inc
be transported to the m
Earth where the passing
total eclipse visible. Fo
focal image does not depe
merely upon its focal len
be obtained by using a
small diameter. In son
directly at the Sun, an
caused by the Earth's rot
responding motion of th
image falls. Another m
advantage, is illustrated
a photograph of the horiz
party of the Yerkes Obse
lina, on May 28, 1900.

The essential feature
12 inches in diameter, w
zontally through a long
parallel to the Earth's a
driving-clock, the mirror
in 48 hours. Such a moti
counteract the effect of th
the Sun's rays reflected in
period. After leaving the
a 6-inch photographic le
sensitive plate at its foc
rotation of the mirror t

position upon the photographic plate, so that any d
exposure may be given.

With this apparatus some remarkably fine photogra
the corona and prominences were obtained by Barnar
Ritchey, of the Yerkes Observatory party (Plate X
During the 87 seconds of the eclipse seven exposures
made, ranging in length from $\frac{1}{2}$ second to 30 seconds. S
of the photographic plates used were 25×30 inches i
To facilitate rapid handling, they were mounted on a w
carrier 15 feet long, free to move on ball bearings on
rails extending at right angles to the tube through th
tire length of the photographic house. A catch, operat
hand, served to stop the plate-carrier at the proper po
for each exposure.

The solar prominences are seen at total eclipses
Sun, projecting like red flames beyond the dark edge
Moon (Plate XXIX). With our present knowledge of
phenomena, it seems hardly possible that just prior
middle of the last century they were regarded by
observers as the illuminated summits of lunar moun
Their truly solar origin was conclusively demonstrat
1860, when they were photographed by Secchi and
Rue, and were shown not to share the motion of the
At that time, however, no conclusions could be drawn
their chemical composition, and it was not until 186
their gaseous nature and their connection with the
became known through the use of the spectroscope
was then found that these immense masses of hydroge
helium gas rise from a sea of flame (the chromosphere,
completely envelops the Sun), and sometimes attain
tions of hundreds of thousands of miles.

The rarity and brief duration of total eclipses would
limited greatly our knowledge of the prominences, ha
Janssen, Lockyer, and Huggins devised an epoch-m

method by which they ca
spite of the glare of ou
instrument which permits
the spectroscope, used
in conjunction with a
telescope. The prin-
ciple of the method is
simple and easily un-
derstood. The white
light of the sky, when
passed through the
spectroscope, is drawn
out into a long rain-
bow band, and there-
by greatly reduced in
intensity. The light
of the prominences,
on the contrary, is
concentrated in the radiat
helium gas, and the dis
merely separates more a
which correspond to thes
feebling them. With the
visible, since their image
persed background of sky

Plate XXX shows a
serving the spectra or th
sunlight.[1] This spectros
(*s* in the accompanying
tangentially or radially
lens, *l*, which renders pa
the slit; a plane grating,

[1] This spectroscope, here show
used as a spectroheliograph with th

the inch; and a second lens and eye-piece, *t* and *e*, form the observing telescope. The grating diffracts the which reaches it from the collimating lens, and prod spectrum, an image of which is formed by the lens *t*, focal plane of the eye-piece *e*. If it is desired to photo the spectrum, the eye-piece may be replaced by a se plate.

If we wish, for example, to observe the spectrum chromosphere with this instrument, the slit, about 1/ of an inch wide, is made exactly tangential to the solar i Under these circumstances the observer at the instr will see the spectrum of the bright sky near the Sun, is of course merely the spectrum of reflected sunlight, therefore crossed by all of the dark Fraunhofer lines. case of substances which are present in the chromosphe lines of the spectrum will be *reversed* from dark to bri regions which correspond to the section of the chromo lying upon the slit. The most conspicuous bright line observed in this way are the hydrogen lines *Hα* (red (blue-green), *Hγ* (blue), and *Hδ* (violet), and the br yellow helium line D_3.

The history of this helium line affords an inter illustration of the intimacy of the relationship whic unites terrestrial and solar chemistry. In his first ob tions of the spectrum of the prominences, made in Lockyer was attracted by the presence of a bright line yellow, not far from the position of the D_1 and D_2 li sodium. This line was designated as D_3, but all attem identify it among the lines of known elements were cessful. Accordingly, it was assumed to represent a ne probably very light, on account of its association with l gen at great elevations above the solar surface. L gave the name "helium" to this gas, because of its origin. In 1895 Ramsay, while engaged in an anal

the mineral cleveite, disc
found to give a yellow li
spectroscope he employed
mine the position of the li
proved beyond a doubt, a
actually in the position o
companion to this line, c
had never been observed i
ination of D_3 in the prom
wood Observatory immed
description of his laborat
presence of a similar comp
measures to agree well in
tions. The companion wa
observations made witho
may be said, however, tha
facilitated by the presen
which D_3 was beautifully
tected the duplicity of th

As was anticipated by
found to be the lightest o
Further study of the spe
a series of lines, other me
in the chromosphere. Ma
of "Orion" stars, which h
say's discovery, are also d
able that other new elemen
are represented by some
spectrum.

While the lines of hy
liant and conspicuous tha
of the chromosphere, it is
number of lines due to o
good day with a powerful

vapors of magnesium, iron, and several other substance conspicuously represented by bright lines in the chr spheric spectrum; but these lines are shorter than tho hydrogen and helium, since the vapors do not rise to so a height. With the Yerkes telescope it is even possib observe a multitude of fine bright lines due to the vap carbon, which lies in close contact with the photosp The layer of carbon vapor is so thin that the least m of the solar image, or a very slight disturbance of the at phere, are sufficient to render the lines invisible.

A total eclipse affords a most favorable opportuni determine photographically the depths of the several la The simplest way of accomplishing this is to place a p over the object-glass of a telescope, which is directed to the Sun. When, at the moment of totality, the Moon c the photosphere, arcs of the chromosphere are left proje beyond the Moon's edge. After passing through the p the image formed on the photographic plate will appear that reproduced in Plate XXXI, which was taken by Lo the eclipse of 1900. The arcs represented here corres to the various lines in the spectrum of the chromosp In this case, however, since no slit was used in the spe scope, the form of each arc is defined by the distributi the corresponding vapor. If a prominence is present at point, its image will be repeated in each of the arcs re senting the element it contains.[1] Of course, this "spec of the flash," first observed by Young, and so called on acc of its brief duration, can be photographed only during th seconds while the Moon's edge is passing over the chr sphere.

It will now be seen more clearly how the forms as we the spectra of the prominences can be observed by the

[1] The prominence group shown in Plate XXIX is faintly represented (reversed in position) in each of the two stronger arcs.

troscopic method withou
slit is employed, the spe
having the same form
straight, the lines will
chromosphere or promin
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curvature. In other wo
matic images of the slit.
the lines will assume the
sphere or prominence w
as though one were lool
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The application of th
of the chromosphere and
solar research. Daily
great enthusiasm by L
astronomers in Europe a
prominences could be d
or cloudlike, and eruptiv
numerous, and may alwa
bers, at the Sun's limb.
sometimes persist for da
the solar rotation. Whe
conditions, the complex
those of the clouds in o
prominences change ver
shooting up to elevations
in a few minutes (see Pl
quiescent forms, they are
sun-spot activity. They
latitudes, though the q
parts of the solar circu
of these phenomena will

CHAPTER XI

THE SPECTROHELIOGRAPH

THE spectroscopic method, as applied by astrophys in various parts of the world, has yielded a nearly contin record of the solar prominences extending back over than thirty years. For many purposes such a reco entirely satisfactory, and permits important conclusio be drawn. But the process of observation is not only and painstaking: it is subject to the errors and uncertai that necessarily attend the hand delineation of any ob seen through a fluctuating atmosphere. Moreover, cha in the forms of eruptive prominences are frequently so that the draughtsman cannot record them. It was princi in the hope of simplifying the process of observation, a rendering it more rapid and more accurate, that the spe heliograph was devised at the Kenwood Observator 1889.[1]

The principle of this instrument is very simple. object is to build up on a photographic plate a pictu the solar flames, by recording side by side images o bright spectral lines which characterize the luminous g In the first place, an image of the Sun is formed by a scope on the slit of a spectroscope. The light of the Sun, transmission through the spectroscope, is spread out i long band of color, crossed by lines representing the va elements. At points where the slit of the spectroscope pens to intersect a gaseous prominence, the bright lin hydrogen and helium may be seen extending from the

[1] It was subsequently learned that the method embodied in the spectr graph had been suggested by Janssen as early as 1869, reinvented by Br Kalocsa, and actually tried by Lohse at Potsdam. But it had not proved a s

of the prominence to its o
lines, corresponding to di
image of the prominence,
photographic plate, it is o
resentation of the form of
plish this result, it is nec
move at a uniform rate a
scope, and, with the aid o
place of the ordinary eyep
one of the lines, permitti
from no other portion of
second slit to a photograp
at the same speed with wh
the first slit, an image of
upon it. The principle of
graphing the prominence
all light is excluded excep
prominence itself. It is
solar image and photogra
to the spectroheliograph
fixed solar image and plat

This method, when fir
tory in 1890, proved un
was partly due to the f
employed. This line, th
tography of prominences
graph of the present day
amidst the difficulties wh
ments. Accordingly, wh
later at the Kenwood Obser
an attempt was made, thr
of the violet and ultra-viol
trum, to discover other li
ments. In the extreme v

broad dark bands which form the most striking feature solar spectrum, two bright lines (H and K) were foun attributed to the vapor of calcium. They had prev been seen visually by Young, but, on account of the ir tiveness of the eye for light of this color, they could observed satisfactorily. A careful study soon showed to be present in every prominence examined, at elev above the solar surface equaling or exceeding those at by hydrogen itself (Plate XXXII, *a*). Their suitabil the purpose of prominence photography is due to s causes, among which may be mentioned their excep brilliancy, their presence at the center of broad dark which greatly diminish the brightness of the sky spe and the comparatively high sensitiveness of photog plates for light of this wave-length.

While fairly efficient from an optical point of vie spectroheliograph of the preceding year had possessed mechanical defects. It sufficed to give photograp individual prominences, but they were not very satisfa In a new instrument, devised for use with the 12-inch wood telescope, the principal defects were overcome means of securing the necessary conditions of the e ment were provided. The Kenwood spectroheliogra shown in Plate XXXIV. In this instrument the solar and photographic plate were fixed, while the first and s slits were made to move across them by means of a s of levers, set in motion by hydraulic power. The first of the instrument, made in January, 1892, were ex successful, and the chromosphere and prominences surr ing the Sun's disk were easily and rapidly recorded (III, XXXV, and XXXVI). The details of their str were shown with the sharpness and precision charact of the best eclipse photographs. And the opportuni making such records, previously limited to the brief

tion, never exceeding se
at once indefinitely exte
study photographically t
escent, cloudlike promin
the rapid changes of vio

But even before this
been accomplished, the
much more important
presented itself. A pho
various portions of the S
at many points of great
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tion of bright H and K li
b and *c*). Some of thes
known to exist through
Young, who had observ
vicinity of sun-spots.
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by such means. What
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consideration of the res
study of the disk, it ap
application of the spectr
new direction.

Before describing thi
ment, it may be well to
when seen with a telesc
ordinary manner without
graphs like that reprod
most conspicuous feature
as the eye can detect, a
bright faculae, which ris
spicuous when near the

invisible when they happen to lie near the center of the
The bright H and K lines, referred to in the last parag
were found in close association with the faculae, a
appeared probable that much of the highly heated cal
vapor, to which these bright lines are due, rises fron
interior of the Sun through the faculae. It was ther
to be expected that a successful application of the spe
heliograph to the photography of the luminous cal
clouds would give bright forms resembling those of
faculae. Furthermore, it was to be hoped that these bril
clouds could be recorded, not only near the limb of the
but also in the central part of the disk, since the b
reversals of the H and K lines were equally well pl
graphed in all parts of the image.

The results of the first experiments, which were ma
the beginning of 1892, were such as to justify fully
expectations that had been entertained. It was at once f
possible to record the forms, not only of the brilliant cl
of calcium vapor associated with the faculae, and occu
in the vicinity of sun-spots, but also of a reticulated s
ture extending over the entire surface of the Sun.
earliest use of the method was made in the study of
great sun-spot of February, 1892, which, through the
scale of the phenomena it exhibited and the rapid cha
that resulted from its exceptional activity, afforded the
conditions required to bring out the peculiar advantag
the spectroheliograph. In the systematic use of the in
ment continued at the Kenwood Observatory through
following years, a great variety of solar phenomena
recorded, and the changes which they underwent from
to day—sometimes, in the more violent eruptions,
minute to minute—were registered in permanent f
During this period, which ended with the transfer of
Kenwood instruments to the Yerkes Observatory, over 3

photographs of solar p
systematic study of thes
the heliographic latitude
(subsequently named the
disk were measured from
mination of the rate of t
has been made. This s
the sun-spots, complete
solar equator than at
words, the Sun does not
rather like a ball of vap
understood.

In this first period
had therefore permitted
objects. It had provid
photographing the solar
gave results hardly inf
brief moments of a total
of recording a new class
exist only through glimp
vicinity of sun-spots, b
either visually or on pho
It was not difficult to s
the new method were m
by the work so far acco
our knowledge of the fi
would be greatly increa
photographing a much
heliograph of improved
evident that other appli
the use of different spe
principles which had n
earlier work, might re
were, indeed, made to p

dark lines of hydrogen, but the Kenwood spectrohelio was not well adapted for this purpose.

The 40-inch telescope of the Yerkes Observatory vided the first requisite for the new work—namely, a solar image, having a diameter of 7 inches as compared the 2-inch image given by the Kenwood telescope. construction of a spectroheliograph large enough to p graph such an image of the Sun involved serious difficu but these were finally overcome. The Rumford spe heliograph, designed to meet the special conditions o new work, was built in the instrument shop of the Y Observatory, and is now in daily use with the 40 telescope (Plate XXXVII).

In this instrument the solar image is caused to across the first slit by means of an electric motor, v gives the entire telescope a slow and uniform motic declination. The sunlight, after passing through the slit, is rendered parallel by a large lens at the lower e the collimator tube. The parallel rays from this len upon a silvered glass mirror, from which they are reflect the first of two prisms, by which they are dispersed i spectrum (Plate XLI, Fig. 1). After passing throug prisms, the light, which has now been deflected throu angle of 180°, falls upon a second large lens at the end of the camera tube. This forms an image of spectrum at the upper end of the tube, where the se slit is placed. Any line in the spectrum may be mac fall upon this slit, by properly adjusting the mirror prisms. Above the slit, and nearly in contact with it photographic plate is mounted in a carriage, which ru rails at right angles to the length of the slit. The rail covered by a light-tight camera box, so that no light reach the plate except that which passes through the se slit. While the solar image is moving across the first

the plate is moved at the
a shaft leading down th
connected, by means of
plate-carriage.

Photographs of the s
under good atmospheric c
details (Plate XXXVIII
shown by these plates
clouds of calcium vapo
diameter, separated by d
in appearance the well-k
sphere (Plate XXXIX).
be drawn between this ap
the eye at the telescope, a
In accordance with Lang
solar surface is resolved u
vation are the extremities
Sun's interior. They s
convection currents, pro
up highly heated vapors
becomes low enough to
be anticipated that out
columns, other vapors, le
to rise, and that the gr
the spectroheliograph
thus ascending from the
indeed, go a step farther
calcium clouds to be cons
passing upward through
times extending out int
means of research now
another application of
new principle, seems con
question.

Mention has already been made of the faculae, which simply regions in the photosphere that rise above the nary level. Near the edge of the Sun their summits above the lower and denser part of that absorbing atmosphere which so greatly reduces the Sun's light near limb, and in this region the faculae may be seen visu At times they may be traced to considerable distances f the limb, but as a rule they are inconspicuous or wh invisible toward the central part of the solar disk. Kenwood experiments had shown that the calcium v coincides closely in form and position with the faculae, hence the calcium clouds were long spoken of under name. In the new work at the Yerkes Observatory the ferences between the calcium clouds and the underl faculae became so marked that a distinctive name for vaporous clouds appeared necessary. They were there designated *flocculi*, a name chosen without reference to t particular nature, but suggested by the flocculent appear of the photographs.

In order to analyze these flocculi and to determine t true structure, a method was desired which would pe sections of them at different heights above the photosphe be photographed. Fortunately there is a simple means (described by Deslandres) which appears to accomplish apparently difficult object. At the base of the flocculi calcium vapor, just rising from the Sun's interior, is c paratively dense. As it passes upward through the floc it reaches a region of much lower pressure, and during ascent it might be expected to expand, and therefor become less dense. Now we know from experiments in laboratory that dense calcium vapor produces very b spectral bands, and that, as the density of the vapo decreased, these bands narrow down into fine, sharp l (Plate XLI, Fig. 2). An examination of the solar spect

will show that the H an
the occurrence of this su
ties in the Sun. The br
we designate H_1 and
calcium vapor (Plate X
flocculi) are seen two b
and better defined. Th
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lines are still narrower
cooler calcium vapor at
be seen that the eviden
at various densities in
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low levels without admi
light that comes from th
simply necessary to set
graph near the edge of
to obtain a picture sho
enough to produce a ba
position of the slit. N
can enter the second s
they are incapable of
width.[1]

The great sun-spot o
tunity to try this met
Sections of the calcium
spot-group, correspondi
graphed on October 9,

[1] The bright regions photogr
and may be regarded as essentia
the continuous spectrum of the
formation of the photographic i
extends beyond the boundaries
In any case we should expect th
the faculae, to correspond closely

XLII.[1] The manner in which the vapor at the H_2 level hangs the edge of the sun-spot is very striking, and thoı study should throw some light on the conditions which in such regions. For it is possible, not only to photo sections of the vapor at various levels, but also to asce by the displacement of the H_2 or H_3 line, as photograph a powerful spectrograph, the direction and velocity of m of the vapor which constitutes the flocculi. It is comn found that the vapor is moving upward at the rate of one kilometer per second, though the velocity varies siderably at different points and under different condi

The photographs occasionally show the existence of flc remarkable for their great brilliancy. In these regions e eruptions are in progress. The vapor, rendered h luminous by intense heat or other causes, is shot out the Sun's interior with great velocity. Consequently are rapid changes in the forms of these brilliant reg whereas the ordinary flocculi change slowly, and repr a much less highly disturbed condition of affairs. brilliant eruptive flocculi always occur in active regio the solar surface, and probably correspond with the tive prominences sometimes photographed projecting the Sun's limb. A remarkable instance was recorde the Kenwood photographs, which showed four succe stages of an eruption of calcium vapor on an enormous A vast cloud thrown out from the Sun's interior compl blotted from view a large sun-spot, and spread out in minutes so as to cover an area of four hundred millio square miles.

[1] Although these photographs have been arranged for comparison wi stereoscope, it is to be understood that no stereoscopic effect in the ordinar will be obtained in examining them. The purpose of using the stereoscope is to allow the images to be superposed, thus permitting them to be seen at th point in rapid succession by moving a card so as to cover alternately the two of the stereoscope. Thus the manner in which the calcium flocculi overha penumbra, and sometimes the umbra, of spots can be observed.

Although the erupt
many instances with er
concluded that the qu
with the quiescent, clo
fact, we have good evi
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against the disk.

So far, we have con
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lines would shine with
that, if all light except
dark lines can be exclu
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the vapors correspondin

At this point attenti
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variations in the intensi
no trace of them can
showing only the line
effect is here concerne
the eye cannot detect
various parts of an ex
would become conspic
into a band of consider

records side by side upon the photographic plate a number of images of a line which, taken together, bui the form of the region from which the light proceeds this way the full benefit of the physiological princi derived, and very minute differences of intensity at v parts of the solar disk are clearly registered upo plate.

It is obviously essential in photographing with the lines to exclude completely the light from the conti spectrum on either side of the line employed. The a sion of even a small quantity of this light might comp nullify the slight differences of intensity recorded b aid of the comparatively faint light of the dark line. the second slit cannot be narrowed beyond a certain it is evident that for successful photography with the lines their width must be increased by dispersion i spectroheliograph to such a degree as to make them than the second slit.

The first satisfactory photographs obtained with dark were made with the Rumford spectroheliograph in May, The lines of hydrogen were chosen for this purpos account of their considerable breadth, and because o prominent part played by this gas in the chromospher prominences. In order to secure sufficient width o lines, the mirror of the spectroheliograph was replaced large plane grating having 20,000 lines to the inch. leaving the grating the diffracted light enters the p where it is still further dispersed before the image o spectrum is formed upon the second slit. The effect o prisms is not only to give additional dispersion, but a reduce the intensity of the diffuse light from the grati a most important matter in work of this nature. The h gen lines employed were $H\beta$, $H\gamma$, or $H\delta$, in the green blue, and violet, respectively.

On developing the
evidences of a mottled
resembling in a genera
flocculi, but differing in
calcium flocculi are br
(Plate XLIII). This
photographs, and it was
flocculi are dark, althoug
hydrogen flocculi appe
character, and correspo
calcium flocculi. But i
violent eruptive disturba
flocculi frequently app
LXXII). Such regions
of active sun-spots, whe
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The comparative dark
evidently indicates that
son radiates less light th
after diffusing from the
form mass over the enti
hypothesis is to assume
the flocculi is due to th

chromosphere, where the absorption probably occurs. results of work at Mount Wilson, described in chap. xvi, s to render this view probable. It should be emphasize this point, however, that the explanation of spectroheliogr results offered in this chapter is merely an hypothesis, wh subsequent investigation may not prove to be corr According to Julius, the flocculi are not luminous clouds, the effects of anomalous dispersion of light passing out f the Sun's interior through vapors of unequal density p. 148).

The Rumford spectroheliograph was also used to sec photographs with some of the stronger dark lines of and other substances. But even with the grating the dis sion was insufficient to give thoroughly trustworthy resu except in a very few cases. It was evident that much gre dispersion must be employed in order to realize the full adv tages of the method in future work. Subsequent prog in the development of the spectroheliograph is describe chap. xvi.

Within a short time after the first work at the Kenw Observatory the spectroheliograph came into general Evershed constructed and successfully used one of th instruments in England, and a year later Deslandres, wh admirable work on the spectra of the flocculi was contem raneous with the investigations at the Kenwood Observat undertook systematic research with a spectroheliograph the Paris Observatory. His contributions to the devel ment of the instrument have been very valuable. Ot spectroheliographs are now used daily in India, Sicily, Sp Germany, England, and the United States.

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THE formulation of
Darwin was the result
related investigations,
was not merely to bring
or animals, describe the
appropriate names. To
animals might be of gre
unusual form, and oth
importance to him main
question of developmen
particular specimen to
such relationships must
ish, the interest of the i
distinguish species. Ha
he may detect, through
modifications of form
ciable, the evidences o
prime object of his sear

Similar tendencies to
shown themselves in eve
tive undertakings on a
best efforts of scientific
common at the present
dicted that the future
and that the various ag
to advance science will
tive manner.

In astronomical and

nities for co-operation and correlation are unusually g and have yielded many important results. The impossil of completing at any one observatory the extensive in gations required for the solution of large cosmical prob and the advantages which may result from the discussi observations made simultaneously or at stated intervals stations differing widely in geographic position, altitud climatic conditions, render co-operation essential in l cases. Plans for international co-operation in solar res are mentioned elsewhere. An attempt to provide fo closest possible correlation of work within a single obs tory is also described in this book.

In establishing an observatory, either one of two pol both represented in existing institutions, may be ado On the one hand, attention may be directed to the pro tion of individual researches or extensive routine inves tions, not necessarily closely related to one another, but constituting an important contribution to knowledge. the other hand, a single large problem may be chosen all individual investigations planned so as to lead as dir as possible toward its solution. The observations req may be very diverse, and cover a broad field. Each, ever, to be most effective for its purpose, must be chosen special reference to the existing needs, and the general gramme must be revised from time to time, in the lig every important advance.

The Yerkes Observatory may serve as an example c institution in which extensive individual investigat differing widely in character, comprise the programn research.[1] Its scheme of work was based on a delib intention to realize the fullest possible advantages of 40-inch refractor in the diverse researches for which

[1] In the astrophysical work, however, an effort was made to correlate th stellar, and laboratory investigations.

peculiarly adapted. T
Observatory of the Car
centrate its entire atte
the problem of stellar e

After the spectroheli
wood Observatory, it s
capable of further exten
better instrumental fa
The establishment of the
to offer the best prospec
of purchasing two dis
40-inch refractor was e
been ordered three year
on Mount Wilson in s
dence in the light of su
available for the comp
glass disks, then in the
obtainable. The oppor
disks were of the larges
glass. After several u
funds from other source
Charles T. Yerkes by P
nified his desire to prov
refractor. The glass
with Clark to complete
ordered from Warner
Yerkes Observatory wa
in 1897.

The gift which provi
made before the Univer
to students. In fact, th
lege, rather than a uni
and the question of the
was still a cause of con

enlarging faculty. A narrow view of the future on the of the trustees might have led to the erection of the c vatory in Chicago, and its use for the purposes of instru rather than for those of research. Fortunately, a diff policy prevailed. It was recognized that the 40-inch scope should be exclusively devoted to investigation, and a site in the immediate neighborhood of the univ grounds would prevent its effective use. It was ac ingly decided to secure a site in the most favorable loc within a reasonable distance of Chicago, and a tra land in Wisconsin, on the shore of Lake Geneva, was f selected.

The plan of the building shows the influence of the Observatory and the Astrophysical Observatory of Pots both of which embody many admirable features. The ad form of a Roman cross permitted the three domes to be rated to such an extent that they practically do not int in the least with one another (Plate XLIV). The des the donor for an ornate structure, and the decision c architect to introduce rather florid embellishments of cotta, led to the use of brick as a building material. Thi quite in accordance with convention, but in conflict wit condition, well known to astronomers, that the temper within an observing-room should be as nearly as possib same as the temperature of the outer air. The massive wall of the great tower in which the 40-inch telesco mounted is therefore decidedly inferior to a light steel struction, with a thin metallic wall, shielded from the Su an outer wall of similar type. Architectural considera however, have weighed as heavily in nearly all of the w largest observatories, and the complete freedom of a subsequently experienced at Mount Wilson, had not yet attained.

The engineering problems presented by the great

of the Yerkes telescope,
mounted, were such as
firm as that of Warner
intrusted. The admira
Yerkes telescope show t
by them in constructing
rising-floor, after sever
had been remedied, als
tested by continuous us
ten years, the entire p
reflect much credit upo

The 40-inch telesc
Yerkes Observatory, ha
chapters, but a few ad
The object-glass, which
before the death of Alv
celebrated firm of Alva
lenses. The outer lens
vex in form (Plate XL
the other by a distance
cave, and made of flint
in the two lenses is a
disks, from which the
were made by Mantois
ordinary purity and tra
absorbs much light, on
(about three inches in
ferent from those of a
perfect glass is require
reflected from a layer o
therefore suffers no abs
light is lost in reflect
out that refracting and
peculiar advantages and

YALE OBSERVATORY

the other must depend upon the needs of the work for v
it is required.

In order to direct the 40-inch telescope to a faint
the sidereal time, as well as the right ascension and de
tion of the star, must be known. After the opening i
dome has been turned toward the proper quarter o
heavens, the telescope is moved in right ascension (
around the polar axis, which is parallel to the Earth's
until the hour circle, attached to this axis, indicate
proper reading. This reading is determined by takin
difference between the sidereal time and the right asce
of the star. The result gives the distance of the star
the meridian, expressed in hours and minutes of time.
motion of the telescope in right ascension is produce
means of an electric motor, controlled by a rope running
the north face of the iron column and easily reached
the rising-floor. The next operation is to move the tele
in declination (i. e., around an axis at right angles t
polar axis) until the declination circle indicates the p
reading, so many degrees north or south of the equator.
the eye-end of the telescope is then too high to be rea
by the observer on the rising-floor, the floor is raise
means of an electric motor, controlled by a switch nea
telescope column. An adjoining switch controls the n
which turns the dome. On looking into the eye-piec
star will be found in the field, provided the setting has
accurately made. The telescope is next clamped in
ascension and declination. It will then be carried by
driving-clock, which causes the polar axis to rotate thr
a complete revolution in twenty-four hours. The app
motion of the star in the heavens is thus counteracted,
the image remains fixed in the field of view, where it
be studied in any way desired.

If, for example, the observer wishes to measure the

tion of the star with r
hood, this is accomplish
in which a fine spider l
sary distance by a micr
sion of the micrometer
determined by measuri
stars, whose positions
of a meridian circle.
of double stars with th
the accurate micrometri
rating the stars of each
joining the two stars,
line in the heavens, is
aid of a divided circl
account of the large ap
to separate with it stars
apart, provided the at
good for the purpose.
images in the principal
case, amount to but lit
an inch, it is obvious th
for such exacting work.

Barnard's observatio
involved the constant us
the work, and the patie
gined when it is rememl
positions of hundreds of
as that illustrated in B
observer remains stand
should also be remembe
perature sometimes falls
sin winters. It is evide
devotion on the part of
accurate measures, nigh

We have already seen (in chap. xi) how the Run spectroheliograph is used with the Yerkes telescope. A spectroheliograph weighs about 700 pounds, and mu attached each morning and taken off at night, special arr ments are required to facilitate this work. Each h instrument used in conjunction with the telescope is mo on a carriage, which stands on the rising-floor. Whe change is to be made from one attachment to anothe floor is raised to its highest position and the telescope firmly anchored to it by means of a steel bar. This obviate any danger of accident when the balance of the is temporarily disturbed. The carriage bearing the spe heliograph is brought to the eye-end of the telescope spectroheliograph clamped to its supporting ring, and 700 pounds of iron weights removed from the tele tube. This restores the balance, which must be adj to a nicety.

The Bruce spectrograph (Plates XLVI and LXXV is used by Frost for the photographic study of stellar sp The image of a star is formed on the slit of the spectrog which is about one-thousandth of an inch in width. light then passes to a collimator lens, which renders the parallel. Three large prisms, next traversed by the bend them through an angle of 180° and disperse into a spectrum. The camera lens forms an image o spectrum upon the photographic plate. Throughou exposure, which may be continued several hours, the server watches the star image and keeps it accurate the slit, any imperfections in the driving of the tele being corrected by means of electric slow motions. In to eliminate the effect of the changing temperature i open dome, the spectrograph is inclosed in a tight-fi case, the interior of which is maintained at a uniform perature by electric-heating coils.

In order to determ
spectrum, a suitable co
is obtained by passing
titanium or iron and
spark on each side of
one of Frost and Adam
this way, is reproduced
the lines of the comp
distance toward the red
sponding lines in the st
of the star away from
amounts to 28 kilomet
orbital motion, the Ea
this date at the rate of
velocity of η *Leonis* w
meters per second.

Such displacements
of determining whethe
from the Earth. This
gins, was successfully
Vogel, and subsequentl
applied it with remarka
In the hands of Campbe
the discovery of many "
in which the componen
velocities that they pe
spectra. In most of t
is a dark star. Our on
nished by the fact that
respect to the compa
toward the violet when
the red when it is reced
chapter it will appear
are used in the study o

The Rumford spectroheliograph and the Bruce spe
graph were constructed in the instrument shop of the Y
Observatory. It had long been customary for observat
to provide means of repairing their own instruments, bu
work of construction had, as a rule, been left to the pr
sional instrument-makers. At the Yerkes Observatory a
equipped shop was not only a convenience, but a neces
The funds given for the establishment of the observatory
not provide for a general equipment of minor instrum
In the absence of the means of purchasing instruments
only alternative was to construct them. Fortunatel
number of machine tools had formed part of the equip
of the Kenwood Observatory and were immediately avail
The appropriations of the University of Chicago permit
skilled instrument-maker to be regularly employed, and
cial gifts, received from various sources in subsequent y
sometimes enabled us to keep several men at work.
instrument shop, at first under the direction of Wadsw
and subsequently under Ritchey (who was in charge o
optical shop from the beginning), proved to be indispens
to the success of the Observatory's work. Not only the in
ments already mentioned, but also the 2-foot reflector,
Snow telescope, a $3\frac{1}{4}$-inch transit instrument, spectrosc
and other apparatus used in the laboratory, and many sp
instruments and appliances employed with the 40-inch
scope and in other departments of the work, came from
source. It may be said that in a large astrophysical obse
tory, where new types of instruments are constantly b
devised, a well-equipped instrument shop is essential if
best results are to be obtained. This is largely becau
the advantage of having the instruments constructed u
the immediate supervision of the men who are responsibl
their design.

The optical shop was another feature of the Ye

Observatory which cont
to its work. Here Ritc
concave, and convex—
2-foot reflector, and oth
a large part of the wo
subsequently transferre
methods employed in g
described in chap. xxiii.
them here. It may b
investigations set on f
not have been underta
afforded by the optical

Still another feature
was subsequently repe
Wilson, is the spectro
solar and stellar phen
Apparatus for producin
air, in liquids, and in c
circumference of a circu
provided, the purpose
means of varying, betw
temperature and pressu
ment, in which the meta
radiations. By setting
mounted at the center
can be reflected to a con
the source on the slit of
The most extensive sing
tory was a study of the
compressed gases, to
temporary stars.

In the diversified w
desire to attack the prob
effective manner was n

large concave grating of the Kenwood Observatory furnished convincing evidence of the advantages of instruments mounted on piers, and the beautiful resoluti the solar spectrum with this apparatus made observatio stellar spectra with small prism spectroscopes seem uns factory. It was felt from the first that every effort shou made to devise a telescope capable of bringing a large well-defined solar image, or a sharp and brilliant st image, into a laboratory, where it could be observed t best possible advantage, with appliances too large or heavy for use with moving telescopes. It seemed clear if this desire could be realized, and if the full advant of reflecting telescopes for astrophysical research coul attained, the means thus provided should render possi well-directed attack on the problem in mind.

The work of the Rumford spectroheliograph showed the further development of this instrument must invo considerable increase in dispersion, so as to permit the of the narrower dark lines. This meant an instrume large dimensions, necessarily to be mounted in a fixed tion, since it could not be attached to a moving teles tube. Another piece of work pointed to the same req ment. At the Kenwood Observatory attempts were ma photograph the spectra of sun-spots, and negatives secured showing a few of the more conspicuous widened l The need of a larger solar image for this work was m the Yerkes telescope. A marked improvement in the p graphs resulted. However, it was clear that photograp spot spectra suitable for the most refined investigations c not be obtained without the use of a spectrograph of r higher dispersion. For satisfactory results a spectrog of at least 10 feet focal length was needed, and this c not be attached to the moving telescope tube. Here, a was another argument for the fixed type of telescope.

The work of construc
ingly taken up. The ori
was modified, through th
tages of the coelostat,
observations. A 30-in
was constructed in th
Observatory. This was
Miss Snow of Chicago,
the funds required for t
nary tests of this instru
images were not very s
admirable results at Mo

In establishing the
Mr. Carnegie gave expr
that some of the most fu
could not be supplied
university must build its
near at hand, rather tha
pheric advantages or the
Its funds, usually given
unavailable, or perhaps
large corps of investigat
the efforts of one of its
ment is projected, the t
supply the financial me
conditions result from
work, and consequently
of even so progressive
Chicago, where the aut
vestigation. The Carn
to the furtherance of r
therefore came about
cordial co-operation of t
vision for the continuati

on foot at the Kenwood and Yerkes Observatories. A
mittee, appointed to report on the advisability of establi
an observatory for solar research, and another observato
observations of the southern heavens, favored both of
projects. A careful test of various sites in the United S
and in Australia, made at the request of the committe
Hussey, led to the provisional selection of Mount W
(5,886 feet), near Pasadena in southern California, a
site for the proposed solar observatory. An appropri
granted by the Carnegie Institution in 1904, furnishe
means of sending an expedition from the Yerkes Observ
to Mount Wilson. The Snow telescope was erected o
mountain, in a new type of house especially designed f
An instrument shop was established in Pasadena fo
construction of the spectroheliographs and other appa
required for use with the Snow telescope. In Dece
1904, the Carnegie Institution decided to establish a
observatory of its own on Mount Wilson. Through
courtesy of the authorities of the Yerkes Observator
the University of Chicago, the Snow telescope was ret
on the mountain, and has since been purchased by the
Observatory. The optical work on the 60-inch mirror, w
was also acquired by the Solar Observatory, was res
by Ritchey in the optical shop at Pasadena. He
designed the mounting for this telescope, and the wo
constructing it was soon undertaken.

CE

ASTRONOMICAL ADV

THE recognition of th
observations at high alti
ton, who wrote as follows

If the Theory of maki
brought into practice, yet
which Telescopes could n
we look upon the Stars, is
by the tremulous Motion of
the twinkling of the fix'd
serene and quiet Air, such
the highest Mountains abo

It will be observed fr
transparent sky is not tl
their passage through
united by a telescope to
different paths, dependi
water or glass, though in
um; i. e., a ray of light
course, and the amount
color of the ray, just as
suffers the greatest refra
viously, then, rays of di
from a star do not pursu
of refraction depends up
since, under ordinary c
ging in an irregular man
and undergoes rapid cha
be momentarily reduced

refraction of the air through which they pass. The
would thus appear blue for the time being. The
instant the intensity of the blue light might be redu
causing the star to seem red. Since the length of the li
path and the degree of refraction increase toward the l
zon, the twinkling of stars, which frequently disappears
gether at the zenith, is most apparent at low altitudes.

As the effect of twinkling is so apparent to the eye,
easy to see that it may be greatly magnified in a teles
and produce serious interference with observations.
star image, instead of being a minute, sharply defined p
usually appears in the telescope enlarged, confused,
tremulous. The component members of close double s
though easily within the resolving power of the telesc
under such conditions may overlap and appear as one. S
larly the minute surface details of the Moon or planets
be entirely obliterated by atmospheric disturbance. It
though the astronomer were forced to observe the heav
bodies from the bottom of an ocean, not calm and tran
throughout its mass, but constantly disturbed by curren
various directions and at different depths, and by irr
larities of density arising from unequal temperatures.

It sometimes happens that excellent definition of
scopic images is obtained through smoke or haze, under
cumstances which might appear to be wholly unsuitable
astronomical work. For certain kinds of observations, w
perfect definition is all important and brightness of the in
of less consequence, the lack of transparency occasioned
hazy air does no harm. But in most classes of work part
suspended in the atmosphere not only reduce the in
sity of the light, but produce serious interference thro
scattering of the rays. The brightness of the sky near
Sun, for example, increases greatly with the number of
or smoke particles in the air. In visual observations of

details of sun-spots this
bility of the prominenc
seen against a brilliant
of stars is also much af

Even on a clear and
brilliant at sea level th
high mountain. For t
medium and reduces, r
brightness of objects s
relative advantages of
1,200 and 6,000 feet
and LVII.

The difficulties in as
atmospheric disturbanc
telescope employed. T
opposite sides of a larg
separated paths than t
They are thus liable to
account of the differen
refraction of the light a
of the air take the form
an aperture which is sm
of these waves, the effe
If, however, several wav
the confusion might be
telescopes require bette

In selecting the site
considerations necessari
that the observatory sh
the university, and this
seriously the favorable
to exist in the extreme
The chosen site has n
immediate neighborhoo

and the brilliant illumination of the sky produced in cities by electric lights, the freedom from vibration a from railways and the heavy traffic of a large city, an facilities for quiet study afforded by the tranquil life c country, were important recommendations of the Geneva site. The observational work of the Yerkes C vatory has been sufficient in amount and quality to that more valuable material can be secured under atmospheric conditions than can be adequately disc without a far larger staff of computers than the obser has ever been able to employ. It goes without saying, ever, that a better site would have been preferable.

But it must not be supposed, from what has been that all mountain peaks would make good observing sta It is true that by ascending into the upper atmosphe astronomer may escape the strong absorption exercis the dense air of lower levels. As one goes up, the become brighter and brighter, especially near the ho since the decrease in length of path is much greater i region than near the zenith. Blue and violet light more from atmospheric absorption than the red, yellov green rays. For this reason, the advantages of high tions, so far as transparency is concerned, are more ap in photographic than in visual observations, since the and violet rays are principally concerned in the prod of the photographic image.

Thus, from the standpoint of atmospheric transpa mountain sites may always be considered to possess a tages for astronomical work. But transparency is a invariably a much less important consideration than s ness of definition, which does not, by any means, d merely upon altitude. In the first place, the geogr location of the mountain in question is a most imp factor. Long periods of continuous clear weather, en

in certain favored regio
of atmospheric conditio
usually prevail. It is
less common; for, if thi
tion, a clear night in on
for astronomical purpo
other. In a region of
another so rapidly that
clear weather the atmos
to a calm, homogeneou
example, the sky is alm
in the year, and the un
by the steadiness of the
velocity. During the
may recur in rapid su
region is disturbed, and
on the beautifully trans
storms are frequently
the United States.

Pike's Peak (14.147
tain site poorly adapted
and July of 1893 I s
with Keeler, engaged i
corona without an ecl
sky, as seen from the
very transparent by ni
favorable for work in wh
consideration. Thus P
the measurement of th
fact that during the
important season for so
capped by clouds thro
On many of the nights
clear, and remained so

ing. Then small cumulus clouds would begin to form i
diately around the peak, and by noon a thunderstorm
be raging, frequently accompanied by a light fall of
In these storms the wind rose to a tremendous velocity,
times as great as seventy miles an hour, and the elec
phenomena were very remarkable. The frequency with
these storms cut off all solar observations, except in the
morning, illustrates the fact that even for work on the
radiation, which requires a clear and transparent sky thr
the greater part of the day, Pike's Peak would serv
poorly, at least during this season of the year. As ma
these storms were confined to the immediate summit
mountain, a station several thousand feet below would
ably offer more opportunities for work than the peak i

But this is not all. The definition of the Sun or st
rarely good on Pike's Peak. This is probably due, not m
to frequent storms and high wind velocities, but also in
to the fact that the summit of the mountain is bare and r
so that heated currents of air rise from the surface and
the definition of the solar image. At this altitude mou
sickness is also very common, and would undoubtedly i
fere, in some degree, with the operation of an observe
The observers at that time stationed there by the We
Bureau informed us that they could not remain o
mountain for long periods without impairment of healt
energy. Two-thirds of the tourists who came to the su
by the railway or on foot, were visibly affected by the
altitude. Another cause of difficulty at the time was
fires in the mountains surrounding the peak, which
volumes of smoke into the air. This rose to a great alt
and destroyed the deep blue of the sky.

The unsuccessful attempts to photograph the corona
renewed on Mount Etna in July, 1894, through the kin
of Professor Riccò, director of the Bellini Observa

of Catania and Mour
Professor Riccò, Signo
nician of the observa
Catania on July 7. A
at Nicolosi, where we sp
from my diary relate
encountered:

July 8. Left Nicolos
(4,760 feet) at $8^h\ 30^m$. E
decrease of white as we
and had excellent view of
still emits vapor. Arrive
The temperature had falle
with clouds. Half an hou
surrounded us until eveni
halo around Moon. Star

July 9. Sky clear, wi
the great crater (which r
of 10,900 feet) away from
of Sicily was dimly visib
brown bank of thick haz
be nearly on a level with
at 9^h, and soon the sky wa
between passing clouds t
changed to west in the af

July 10. Wind blew
sky very white. Observe
with 12-inch telescope. I
became unsteady later.
formed, and Sun was surr
were also noticed in direc
prominences with Profess
at Catania. At sunset wa
Filosofo. Whole sky cov

July 11. Sky very w
atmospheric lines with di
scope, and observed Sun
lation, spots, and faculae

sunset visited Valle del Bove. Sky filled with haze, and almo bright for the eye 10° from Sun.

July 12. Sky very white. Wind still blowing smoke from over Sun. Bank of haze above level of observatory. Observe by projection with Professor Riccò; image unsteady. Climl top of crater, and found sky in zenith of deeper blue than whe from observatory. Whole island enveloped in haze. Desc to observatory by moonlight; double halo around Moon. Obs Moon, Saturn, and several stars with the 12-inch, using pow to 430. Seeing magnificent; images almost perfectly steady highest power. Both Moon and Saturn were very low, but i were remarkably good. With naked eye scintillation was h perceptible in stars higher than 30°.

July 13. Wind blowing from direction of crater, but sk since July 9: cloudless and generally whitish, but increase in b ness toward Sun was gradual. Much dust. Telescope in use $9^h\ 40^m$ by Professor Riccò for daily record of chromosphere. inences very well seen. At $9^h\ 50^m$ broad and brilliant ri whiteness around Sun, making it useless to try for corona. S blowing directly over Sun, and diffusing through entire sky. image observed by projection; definition very poor. At 11^h sk improved, and preparations were made to photograph coron five minutes later more smoke blew over Sun, and sky becam white. Mirror found to be dewed, and surface badly tarnish the sulphurous fumes, though it had been tightly covered moment it was not in use. Sky around Sun remained brigh wind was so violent that no photographs could be made. S sulphurous odor.

July 14. Smoke blowing across sun. Strong sulphurous Whole eastern sky white. Prominences fairly well seen at 7 Left observatory at 3^h, and arrived at Catania about midnigh

As I was assured by Tacchini and Riccò that the s frequently very clear on Etna, it may safely be concl that the difficulties we encountered were exceptional. D the entire time of our stay in southern Italy and Sicil atmosphere was very hazy, and the sky was rarely of a blue. I was told by Galvagno, the custodian of the Observatory, that the smoke this year was much more n

able than usual. If the
of toward, us, the sky w
hardly as blue as whe
first part of our visit th

So much for the re
Sicily and the Rocky
a solar observer requir
very encouraging. M
astronomers have been
and we find Piazzi Smi
omer's Experiment, r
definition at altitudes
His expedition to Ten
purpose of testing the
peak, was the first ser
parency of the air and
were found to be exc
upper atmosphere, an
encountered.

However, good sola
Blanc (15,780 feet), a
in India (7,700 feet),
There is obviously no i
and good solar definiti
various observers on
prevalence of storms
warm air rising from
protected by little or n
the night conditions ar
around the summit are
intensely heated and n
This is a matter of

[1] The attempts to photogra
conditions, but neither this met

Observatory (Plate XLVIII), since the work is confin night observations. The great number of admirable re many of them requiring the finest definition, which been obtained at the Lick Observatory, afford the b evidence that its site was well chosen.

The results of experience in various parts of the would seem to indicate that a mountain observatory, i to enjoy good conditions both by night and by day, s be situated in a climate where the sky is clear continu for periods of several weeks or months, and the average velocity is low. The summit of the mountain, as well slopes, should be covered with foliage, to protect it fro heat of the Sun. Finally, the elevation should be suff to escape the dust which diffuses itself through the the dry season, and the low-lying fogs and clouds frequ encountered in regions near the sea.

C

THE MOUNT W

FROM the preceding
of research of the So
Kenwood a programme
use of the spectrohelio
spectra of Sun-spots and
possible application of
research, was institute
programme was broad
providing ultimately fo
tion; the possibilities
fully realized, through
refractor; and instrum
refractor for the furthe
Snow telescope for sol
for stellar investigatio
wholly constructed. A
in large part to the dev
Mount Wilson Solar O
of stellar evolution, at
advantages.

In brief, the scheme
comprises: (1) solar in
knowledge of the Sun
central body of the s
spectroscopic studies
upon the physical natu
ence to their developm
the interpretation of s

the central problem in mind, each successive researc
designed to occupy a logical place in a concentrated at
proceeding along these converging lines.

The variety of the problems connected with the estab
ment of the Solar Observatory on Mount Wilson affor
good illustration of the diversified work of an astrono
It was necessary, in the first place, to test the atmospl
conditions by means of telescopic and meteorological obs
tions extending over a considerable period of time, in c
to make certain that the site would prove suitable. In
second place, since the summit could be reached only
narrow mountain trail, it was evident from the outset
the question of transporting building materials and the
of heavy instruments would not be an easy one to s
Again, since one of the prime purposes of the new observ
was to take advantage of the possibilities of improved in
ments, the design and construction of the telescopes, spe
scopes, and other appliances would require the solutio
many instrumental and engineering problems, and much
of experiment. It was known, for example, that glass mi
change their form decidedly when exposed to the Sun's
For this reason it was to be feared that they might not
good solar images. This is a matter of fundamental in
tance, since the fixed telescope for solar observations n
sarily involves the employment of mirrors. In additi
these questions, many others, very diverse in character,
sented themselves. These included the preparation
programme of research, adapted for the special requiren
of the new observatory, in which all the investigatio
progress were to be closely correlated; the considerati
the best methods of discussing and interpreting the pl
graphs made with the spectroheliograph and other in
ments; the invention and construction of special measu
and computing machines, etc.

From a meteorologi
may be divided into t
the rainfall is very co
and in almost all respe
astronomical work. T
sidered to extend as far
with much better weat
Lick Observatory, on M
of night-seeing is main
In the southern part of
different from those w
of the state. The light
fewer clouds, a remark
winds.

There can be no do
immediately adjoining
tions for astronomical v
reason it became desira
siderable number of p
tests might have been
the thunderstorms that
the vicinity of Flagstaf
would interfere so seri
region almost entirely
other serious objections
at Flagstaff did not ind
able as in California, a
tive claims of various r

Hussey's tests in t
Mount Lowe, and Mou
and Cuyamaca and P
His observations seeme
would prove to be the
observatory.

Mount Wilson is one of many mountains that form
southern boundary of the Sierra Madre range (Plate XL
Standing at a distance of thirty miles from the ocean, it
abruptly from the valley floor, flanked only by a few spu
lesser elevation, of which Mount Harvard is the hig
Except for a narrow saddle, Mount Wilson is separated
Mount Harvard by a deep cañon, the walls of which are
precipitous. Farther to the west, beyond the saddle lea
to Mount Harvard, the ridge of Mount Wilson forms the u
extremity of Eaton Cañon, which leads directly to the
Gabriel Valley. East and north of Mount Wilson lies
deep cañon through which flows the west fork of the
Gabriel River, and beyond this rise a constant successio
mountains, most of them higher than Mount Wilson, w
extend in a broken mass to the Mojave Desert. The Si
Madre range forms the northern boundary of the
Gabriel Valley, which is further protected toward the
from the desert by the high peaks of the San Bernar
range.

The view from the summit of Mount Wilson is most ex
sive, embracing the whole of southern California, and re
ing out over the Pacific to islands nearly one hundred m
distant. Cuyamaca, about 130 miles to the south, not
from the Mexican boundary, is easily visible. San Bernar
and San Jacinto peaks, the latter 90 miles away, are so
tinctly seen under normal conditions that a station m
easily be established on either of them, for experiment
measuring the velocity of light from Mount Wilson. M
San Antonio (10,080 feet), 25 miles away, has already se
as a station for certain observations of the solar radiat
supplementing the work of the Smithsonian Expeditio
Mount Wilson (Plate L).

During a part of the year, particularly from Apri
August, fog rolls in from the ocean and covers much of

San Gabriel Valley during t
fog-clouds rarely attain elev
mountains of the Sierra M
fog, and during many mont
cally continuous sunshine.
for a part of the day, but
which decreases in passing
tain tops.

Mount Wilson is reache
either one of two trails. On
Trail," ascends from Sierra
The other, called the "Ne
Eaton Cañon, about 6½ mi
9¼ miles long. When our
over two feet in width at its n
grade of about 10 per cent.
transportation purposes tha

Some hundreds of tons
observatory have been taken
of mules or "burros" (donk
parts of instruments, whicl
way, were carried on a spe
(Plate LIII). The running
wheels with rubber tires. T
wrought-iron yokes from t
surface at a height of onl
Steering-gear, of the type
for both pairs of wheels.
the forward wheels, while t
tiller by a man walking beh
horse pulls a load of a thous
out difficulty. With two ho
the lower end of the trail t
pleted with such a load in a

round trips were made with this truck for the purpo carrying the mirrors, lenses, and heavy castings of the and Bruce telescopes, the parts of a 15-H. P. gas en and other heavy machines, as well as the 4-inch pipe col used in constructing the steel skeleton of the Snow tele house.

During the first two years, it was hoped that a rai would be constructed to the summit of the mountain, w a hotel had already been erected. When it finally appe that this hope must be abandoned, we were compelle adopt the alternative of widening the New Trail into a wa road (Plate LIV). This work, which was done durin autumn and spring of 1906 and 1907, was considerably pered by unprecedented storms in December and Jan The snow on the summit of Mount Wilson (Plate LV) five feet deep on a level, and the torrential rains, belo snow line, brought down thousands of tons of earth and from the steep slopes of the mountain. When these dif ties had been overcome, the transportation problem w far solved as to permit the structural steel for the buil and dome of the 60-inch reflector to be hauled to destination.

Our systematic tests of the atmospheric condition Mount Wilson began in March, 1904. An old log c which had been in a state of partial ruin, was rend habitable and occupied until the "Monastery" was pleted, in the following December. Frequent tests o solar definition were made with a 3¼-inch refracting scope, supplemented by meteorological observations.

The specific requirements of a site for an observato be devoted to solar research and the study of stellar e tion are as follows:

1. Excellent definition of the solar image, on many of the year.

2. Excellent definition
telescopes of large apertu
work.

3. Great transparency
for accurate determinati
total heat radiation of t
Earth's atmosphere), an
nebulae requiring very lo

4. Continuous clear w
rendering possible daily
ena, of which an imperfect
from scattered observatio

5. A low average wi
best observing season, to
telescopes employed for p

It is easy to see why t
usually much inferior to
heating of the earth, ca
currents of warm air, whi
above. It has already be
produced by irregular ref
this is caused by irregula
through which the light r
tain peak may have some
extensive level area, beca
follow the mountain side
turbances in the images
evident that this effect wi
tain is bare and rocky, in
with trees and bushes.
most of the slopes of Mo
is much less pronounced
mountains. It is nevertl
reason the best observati

hours after sunrise, and about the same time before su
It is true that great depths of atmosphere must be trav
by the Sun's rays when it is so near the horizon. Neve
less, the image on a large number of days in the sur
season is wonderfully sharp and distinct, permitting
finest details of structure to be observed. The conclu
based upon observations made with the 3¼-inch refr
were afterward confirmed with the large aperture of
Snow telescope, leaving no doubt that with respect to
definition Mount Wilson offers very exceptional advant

The tests of the night definition, and of the transpar
of the night sky, were made by Barnard, during the
of the Hooker Expedition. In chap. v a description
been given of the Bruce 10-inch photographic teles
of the Yerkes Observatory, used by Barnard in his st
of the Milky Way. In order to extend farther south
work previously done with an instrument of 6 inches
ture on Mount Hamilton, Barnard brought the Bruce
scope to Mount Wilson and made with it a remarkable s
of photographs. Mount Wilson (latitude +34° 13′)
south of the Yerkes Observatory, and 3° south of the Lick
servatory. This fact, combined with the great transpar
of the sky, permitted Barnard to photograph regions o
Milky Way which had been out of reach in his earlier v

The best way of comparing the transparency of the
at Lake Geneva and Mount Wilson is by taking two pl
graphs of the same region of the heavens, with the
exposure time, on photographic plates of the same sensi
ness, used with the same telescope, by the same obse
Such a comparison is illustrated in Plate LVI, which re
sents the cluster *Messier 35*. The difference in the numb
stars included on the photograph is a striking illustratio
the advantages of Mount Wilson. Indeed, if this result
not confirmed by many others, and regarded by Bar

as representing a fair
that some difference in
sensitiveness of the pla
the Mount Wilson phot
mer night, while in t
photograph the transp
average there.

An illustration of th
which shows the *Pleia*
the Bruce telescope, w
minutes at Mount Wil
the Yerkes Observatory
graph shows quite as
has a great advantage
much larger amount o
This is due to the fact
the Wisconsin sky tend
photograph. It is inter
will result from the use
fine conditions.

During the long exp
of cross-hairs in the ey
to the Bruce telescope.
tion of the stellar imag
previously explained, th
in any considerable d
atmosphere, but rather
tion. Barnard found
remarkably good, and
firmed with the large a

The transparency
thoroughly tested by
constant" of radiation,
As compared with Wa

of the Smithsonian Astrophysical Observatory has done, the advantages of Mount Wilson are very m Of equal importance for this work is the fact tha observations can be made day after day, with practica interruption, for a period of many weeks. In Washi during the same period, it might be possible to obtai two or three trustworthy determinations. Thus the m in which the solar radiation varies can be shown, in th case, by its daily fluctuations, while in the other it mig wholly concealed.

Finally, the average wind velocity in the dry s proved to be extraordinarily low, not only for an ex mountain-peak, but as compared with a station at any During the rainy season, when there is much cloudy we violent storms, accompanied by high winds, are not u mon. But in the dry season an almost dead calm freq prevails at night, and also during the early morning observations. In the later hours of the day there is u a light breeze. The typical condition on Mount W during the dry season may be described as a perfectly less sky, and so little breeze that the leaves are l stirred by it.

It would be tedious to discuss the other conditions as the heavy growth of foliage, the presence of abu springs of water, the neighborhood of large cities, etc., contribute toward the advantages of Mount Wilson observatory site. The astronomical tests have been des in detail because they illustrate the practical beari atmospheric conditions on astronomical observations.

CH

THE S

Léon Foucault appe
ciate the advantages of a
a solar or stellar image w
stat, constructed by Eich
in 1868, the year of Fou
Paris Observatory, where
Deslandres for solar phot
Sun this instrument gave
fection of the driving ca
less from a fixed position
in almost all types of fi
the inconvenience that
siderostat or heliostat rot
would cause distortion in
fixed spectroheliograph.

It is not easy to see
forms, was not more rapi
tions, its practical appli
heliostats of various type
into the laboratory, but r
Sun. In other words, tl
an instrument of precisi
well-defined solar image,
in position, until the *coe*
poses, about ten years
invented long before, bu

[1] The great *equatorial coudé* o
of a fixed telescope, but I do not th

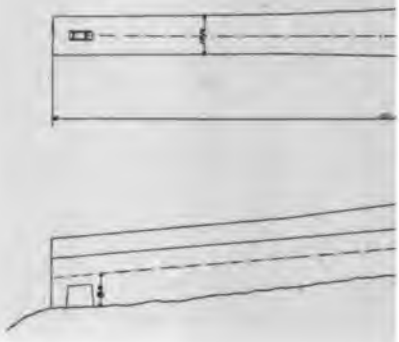
simplicity of its construction, the ease of driving it w precision as great as in the case of the equatorial refra and, above all, the fact that the solar image produced does not rotate, had been overlooked. At Turner's sug tion it was employed for eclipse purposes, at first by of the English parties, and subsequently by astronome all parts of the world.

However, the conditions under which eclipse observa are made are very different from those that obtain in nary solar work. A defect of the coelostat is that the d tion of the beam of light reflected horizontally from mirror varies with the declination of the Sun. During few minutes of a total eclipse the Sun's declination does change appreciably, and the telescope into which the is reflected by the coelostat stands fixed in position. in solar observations continued throughout the year direction of the reflected beam is constantly changing the Sun moves north or south of the equator. As it w be inconvenient to swing the long telescope tube, whic pointed at the coelostat, around through the necessarily l angle, a second mirror must be introduced to receive light reflected from the coelostat mirror and send it in desired direction. About once a week, or sufficiently to cause no appreciable loss of sunlight, the second m is moved a short distance, so that it may continue to rec all the light of the reflected beam, in the changed pos given it by the variation in the Sun's declination.

Another difficulty of the coelostat, which is commo all forms of heliostat, but plays no part in total-eclipse w is the distortion of the mirrors by sunlight. This obs is really the only serious one presented by this forr telescope. How it has been met at the Solar Observa is explained below.

The Snow telescope, the optical and mechanical part

which were constructe
shops of the Yerkes
LVIII. This photogra
able second mirror, wh
mirror of 60 feet focal
The general arrangeme
Mount Wilson, is indic



Plan and Elevation of

on a carriage, which c
line *aa*. On account
which falls rapidly to
make the long axis of
instead of being exact
reason this axis is not l
toward the north. Wit
the conditions of the si
the building would hav
increase of expense.
bearing the second mir
axis. The coelostat mi
second mirror, 24 inch

and serve merely for bringing the sunlight into the tele house. The plane of the coelostat mirror is parallel t Earth's axis, and the mirror can be rotated around this once in forty-eight hours, by means of a driving-clock. exactly counteracts the motion of the beam due to the S apparent motion through the heavens.

From the second mirror the light passes to either o two concave mirrors, each 24 inches in diameter (Plate L One of these, which has a focal length of 60 feet, is supp on a carriage so that it can be moved (for focusing) a the rails *cc*, which are mounted on the small pier shown the middle of Fig. 5. This mirror produces an i of the Sun about 6.7 inches in diameter, at a position i spectroscope house determined by the angle which the cave mirror makes with the incident beam of sunlight the mirror stood normal to the beam, the sunlight woul reflected directly back upon itself toward the second mi If, however, the concave mirror is turned slightly to one the solar image can be formed at the end of the pier *f*, w the 5-foot spectroheliograph stands. By moving the m back toward the north, along the rails on which it slides image can be brought to a focus on the pier *i*, where th and photographic plate of a Littrow spectrograph, of 18 focal length, are mounted. Again, by rotating the con mirror so as to return the beam in a somewhat different d tion, the solar image can be sent into the constant tem ture room *lll*, where the bolographic apparatus, for stud the heat radiation of different parts of the Sun, is mou on the massive triangular pier *kkk*.

If a larger solar image is required, the mirror of 60 focal length is moved out of the way, and the beam fron second mirror allowed to pass to a concave mirror of feet focal length, mounted on a pier at the extreme r end of the telescope house. The image of the Sun is

formed at the pier *g*. This image is 16 inch special study of solar required.

The remarkable co contrasted with a grea telescope, is immediatel heavy instrument, one scope tube, it is set u adjustments need never pass rapidly from one i the forms of the calc spectroheliograph, and with the powerful Lit importance of studyin neously by various me observations, the adva will be easily recognize

The peculiar form o is mounted calls for a experiments, some of w the spring of 1904, the turbance of the definit the ground in the imm could be appreciably r at a considerable heigh scope supported in a tu feet, seemed to leave second consideration, particularly emphasized stat telescope, having a of ventilation, was the r the temperature within possible the same as tha

if this condition is not met, the mixture of air of diffe temperatures at the open end of the house, through wh the beam enters, will cause irregular refraction and co quent disturbance of the image.

Plate LX shows the pier on which the coelosta mounted, at a height of nearly 30 feet above the grou Since the parallel rays from the coelostat to the conc mirror pass through a closed house, it is not essential that part of the building should stand high above the ground. is important, however, that disturbances due to heatin the walls, caused by sunlight falling upon them, be obvia For this reason all parts of the building, including movable shelter, the spectroscopic laboratory, and the l narrow house extending north from the laboratory, have inner wall and ceiling of canvas, and an outer wall compc of canvas louvers, very completely ventilated. The roo also ventilated, by wooden louvers at the ridge through the entire length of the movable shelter and the north ex sion, and at the peak of the laboratory. Rain and snow prevented from entering the roof louvers by means of car guards, which can be raised or lowered at will. The ho extending north from the laboratory has a floor of can with a space below, through which the air may pass fre

The louvers surrounding the coelostat pier are inten to protect the pier from vibration caused by the wind, from heating by the Sun. The steel structure does not to the pier at any point, and is therefore made rigid enough support itself in high winds. When not in use, the coelo and second mirror are covered by a house on wheels, clo at both ends by walls of heavy canvas. These may be ope so that when the house is moved to the north the coelo stands fully exposed. The movable shelter then fits clo against the south wall of the laboratory, and forms a par the tube through which the beam passes.

In the preliminary t
Yerkes Observatory the
though good images wer
evidence of distortion of
in the first experiments
was experienced. Soon
the Sun it was seen that
as the focus changed, e
distortion of the plane n
appearance of the imag
plane. It was soon found
rapidly after the mirror
because of the greater ab
nished surfaces. Moreo
with a cool breeze than o
then arose whether this

In the early morning,
tion of the Sun is best, th
later in the day. If the
between the exposures of
are made as short as
obtained at this time, and
fore sunset. It has bee
strong blast of air on the
of electric fans, during th
the intervals between the

It must be understood
necessary only when it is
definition of the solar in
used, the average photog
the early morning with t
spectroheliograph are bu
graphs, secured on only a
inch Yerkes telescope an

The best photographs taken on Mount Wilson are distin superior to the best secured in our work with the Rum spectroheliograph. It must not be supposed that no v can be done with the Snow telescope except under the ditions stated. As a matter of fact, very fair photogr can be obtained with the spectroheliograph at almost time during a cool day, and in the early morning and afternoon hours of a hot day without wind. It is necessary to arrange the daily programme of observation that the spectroheliograph, which requires the finest de tion, is used during the period when the seeing is Photographic work on the spectra of sun-spots follows, after this is completed the conditions are entirely satisfac for various other observations, such as bolographic worl the absorption of the solar atmosphere, etc. Some of results obtained with the Snow telescope will be illustr in subsequent chapters.

From laboratory tests, it appears that the distortio mirrors in sunlight is chiefly due to actual bending of glass, the front surface, expanded by the heat, becon convex and the rear surface concave. Radiation from electric heating coil, placed a short distance behind a mir restores its figure, but not perfectly. A much better wa heating the back of a mirror is by reflecting sunlight u it. Perhaps the best plan, however, is merely to incr the thickness of the glass mirrors (p. 235).

C

SOME USES OF S

THE necessity of des
for use as an attachmer
somewhat with its effici
excellent results, but
difficulty of securing p
solar image, are someti
tained with it. Fortun
Snow telescope. It v
satisfactory form of sp
ment is moved as a wh
the photographic plate
graph of this type wa
in attempts to photog
eclipse, from the sumn
ments of moderate din
graph as a whole appea
contrivance for moving
chronism.

A photograph of th
with the Snow telescope,
idea of the general desig
which shows the spectr
before it was completed
cast-iron base, bearing f
which the moving part
steel balls. The cast-ir
optical parts has four
steel balls, but almost

mercury, in three tanks formed by subdivisions in the casting. Wooden floats extend from the lower surfa the iron platform into these tanks, reducing to a mini the amount of mercury (about 560 pounds) required t hold the instrument. The motion of this platform wit spect to the fixed solar image and photographic plate is duced by either one of two screws of different pitch, d by an electric motor arranged to give a perfectly uni speed.

The collimator slit, on which the solar image is for is shown on the right of Plate LXI. On account of the size of the solar image, which is about 6.7 inches in dian the slit is 8½ inches long. After passing through th the light falls upon a large collimating lens 8 inches in d eter, which renders the rays parallel. They then m silvered glass mirror, from which they are reflected to th prisms, of 63½° angle. After being dispersed by the pr the rays strike the 8-inch camera lens, which forms an i of the spectrum on the camera slit (shown near the cent Plate LXI). The optical train thus resembles that o Rumford spectroheliograph, but the lenses and prism so much larger that no light is lost from the circumfe of the solar image.

On account of the great curvature of the spectral produced by such prisms, it would be necessary to empl highly curved camera slit, in case an ordinary straigh were used to admit the light from the Sun. In this e the resulting photograph would be greatly distorted, bec points lying along a straight line on the Sun would ap along a curved line in the photographs. Thus the im instead of being circular, would be shaped somewhat an apple, greatly flattened on one side. By dividing curvature evenly between the two slits the distortio eliminated and the photograph is made circular.

The actual operations
flocculi with one of the
electric arc, the carbons o
a solution of calcium chl
collimator slit. The brigl
in the spectrum of such a
the solar spectrum is diffi
a micrometer screw, the c
one of the lines. Thus t
photographic plate is that
the mirror of the coelosta
by a canvas screen, in o
After the photographic pl
its support in front of th
removed and the solar im
collimator slit, by moving
telescope. The slide of t
the electric motor started.
motor, then causes the ent
slow and uniform rate, so
the solar image and the c
graphic plate.

If it is desired to take
instead of a calcium line, t
until the line in question
the exposure is made as b

In the daily programm
graph with the H_1 line of
low level calcium vapor;
showing the flocculi at a l
of hydrogen; and one wi
early morning and again,
afternoon (Plates LXIII-
clear day after day throug

(on 112 consecutive days in the summer of 1907), and infrequently during the rainy season, the instrument yields a large number of plates, suitable for the compar study of the flocculi.

Photographs of the prominences are also made daily, circumstances permit. These are used to determine changes in number and total area of the prominences du the Sun-spot period.

In the establishment of an observatory much remai be done after successful photographs of astronomical nomena have been obtained. Indeed, although the wo organization must be far advanced before photographs be secured, the most important steps are still to be t For an astronomical photograph, while it may yield r new information from casual examination, is to be rega as a document of great value, worthy of prolonged inv gation. Every photograph of the Sun, for example, r sents its changing phenomena as they were at the mo of the exposure, under conditions which will never be ex repeated. The best methods of obtaining from photogr all the knowledge they are capable of conveying are arrived at only after the fullest consideration of the p bilities.

In chap. xi the most striking characteristics of the culi have been explained and illustrated. We must consider how these objects may be systematically studie such a way as to contribute to our knowledge of the constitution. The most obvious peculiarity of the floc apart from their change in form, is their motion acros Sun's disk. This is due to the solar rotation, which first discovered through the daily motion of sun-spots. is remarkable that the spots do not move as they wou they were fixed to the surface of a solid sphere. Spo different latitudes move with different angular velocities

exhibit what is called
spots near the Sun's e
shorter time than thos
the rotation period is
or south latitude the
45° it is about twenty-
according to results ob
the same general law.
an application of Dop
is not confined to the
by the layer of metallic
lies just above the pho
of the solar spectrum
coming through it fro
to inquire whether the
be clouds of luminous
thousand miles above
of rotation.

The method employ
the spots is to measure
to the center of the Su
or more days, and in
longitude of the same
obtaining the velocities
of rotation can be deri
measuring the latitud
remember that the pla
an angle of about 7°
Earth passes through
plane with the ecliptic
only on these dates do
lines across the disk.
the north and south l
angle" of the Sun's ax

the year—about 26½° each side of zero. It is thus ev
that in determining the latitude and longitude of a sp
ordinary methods of measurement considerable calcul
will be required. The process employed at Greenwic
the direct photographs of the Sun obtained there, is to r
ure the distance of the spot from the center, and the
between the Sun's axis and the line joining the spot
the center of the disk. As the inclination of the Sun's
is known for every day in the year, it then becomes pos
to calculate the latitude and longitude of the spot.

This method is very satisfactory when a comparat
small number of objects are to be measured on each
which is the case with sun-spots. But the flocculi a
numerous, and offer so many points suitable for mea
ment, that the calculations required for each spectrol
graph plate would be very extensive. In seeking to
some simple method of abridging these calculation
appeared that the solar photograph might be proj
upon the surface of a globe ruled with meridians
parallels 1° apart. The axis of the globe being set a
inclination corresponding to the date of the photograp
should then be possible to read off the latitude and long
directly, by estimating the position, in tenths of a de
of the flocculus in question, with reference to the ne
meridian and parallel (Plate LXIX). As the longitu
the center of the Sun's disk is tabulated for each day i
year, no calculations would be necessary, except to ad
subtract this longitude in the case of each of the read

This method proved so satisfactory, when used a
Yerkes Observatory in measuring the Kenwood photogr
that it was afterward adopted, in perfected form, in
Computing Division of the Solar Observatory. The
globe-measuring machine, or "heliomicrometer," is i
trated in Plate LXX. Two 4-inch telescopes, shown i

upper part of the cut, a
glass mirrors thirty feet
light from the spectro
immediately under the
by incandescent lamps
light from a globe, mo
and illuminated on its
and plate, given by the
in a single eye-piece, s
posed. If, then, the
meridians and parallel
described, the position
estimation. However,
higher degree of preci
small and faint flocculi
possible if they were ob
minated surface of the
hairs, which can be mo
vertical direction by th
to coincide with the ob
then illuminated, and r
a point corresponding t
the central meridian fa
circle, which can be re
then shows the angle
turned in latitude. A
longitude from the cent
understood that the axis
measuring longitudes is
date of the photograph.
position of the cross-ha
to the rulings on the (fi

This instrument, wh
the Solar Observatory,

tice. It has been found that the latitudes and longi
thus read off directly, are as accurate as when deter
by measuring the plate in an ordinary measuring-m
and performing the necessary calculations. Since the
urements can be be made quite as rapidly on the he
crometer as on the other machine, all the time requi
make the calculations is saved. Thus one observe
measure a great number of flocculi, and the services o
eral computers are rendered unnecessary.

A discussion of the measurements made in this way
that the flocculi follow a law of rotation similar to that
governs the spots and faculae. It will require some ti
learn whether the velocities of the flocculi differ appre
from those of the spots. It appears probable, however,
results thus far obtained, that the flocculi move with
the same velocity as the faculae. This would be a n
result, since, as already explained, the vapors of the fl
probably rise from the faculae, and lie immediately
them.

The importance of providing for the closest possibl
relation between all of the investigations of the Solar C
vatory has already been mentioned. For this reason s
of the solar rotation should be made with reference to
solar work. The motions of individual flocculi freq
differ considerably from the average motions of the floc
the same latitude. Such differences, in many instance
doubtless similar to those observed in the case of sun-
where they are related to the spot's activity, which
greatly during the course of its development. Howeve
daily motion of a flocculus may also depend upon its h
above the photosphere, and this may vary from day t
It thus becomes desirable to learn whether differences
height of flocculi can be detected and actually mea
For example, do the hydrogen flocculi lie at an average

in the solar atmosphere
flocculi, and, if so, do
velocity that may depe

It has already been
cium flocculi photogra
is employed probably l
form, but somewhat su
when the slit is set on t
obvious, however, that t
culi is above that of the
be determined by accu
dark hydrogen flocculi,
those of the bright cal
there are important diff
With the aid of the ste
factured by the Zeiss
making accurate comp
to observe a hydrogen
calcium photograph, tal
that no appreciable cha
exposures. With the n
the two photographs, in
quick succession. For
permits the eye to see
afterward, the other.
cium flocculus lying ne
of the corresponding hy
view, it is found to be d
of the disk. This is n
On the average, howeve

[1] These photographs were s
the changes in the forms of the
to interfere with the general co
case, however, the changes may
near the spot indicate great ar
details, the photographs must b

be displaced in this way, by an amount representing a of some 1,500 miles above the corresponding calcium c It will therefore be interesting to determine at some time whether the rotational velocity of the hydrogen f differs appreciably from that of the calcium flocculi.

An important step in the interpretation of spectr graph plates will be made when it can be ascertained w anomalous dispersion plays any part in producing th nomena recorded by them. Our present views as nature of Sun-spots, prominences, and other solar phen are based on the assumption that their light reaches us nearly straight lines. If the pressure in the region th which the rays pass is low, this may be essentially t white light. But we know that light of about the wave-length as that of an absorption line in the spectr bent far out of a straight path when it passes throu vapor to whose absorption the line is due. The quences of this fact have led Julius to develop a nev theory, based on the supposition that all metallic va any given distance from the Sun's center are com mixed, but not of uniform density throughout. Unde circumstances the chromosphere, prominences, and f would not exist as we see them, but such appearances be caused by anomalous dispersion of light passi through the vapors from the interior of the Sun. A of investigations, involving solar, stellar, and laboratory is being carried out on Mount Wilson for the purp testing this theory.

The rotation periods of sun-spots may depend upo level, and this raises the old question as to the posi these objects with respect to the photosphere. Acc to the common view sun-spots are saucer-shaped cavi the photosphere. This idea is based upon the obser

[1] This result must be checked on photographs taken simultaneously.

of Wilson, who found t
limb by the solar rotati
the center of the disk,
would be, on account o
it sloped downward to
results do not offer any
thus render necessary a
the question. Ten ye
that the heat radiation
neighboring photosphe
the limb. From this it
must lie above the pho
the influence of the low
reduces the intensity
circumference. It has
sun-spots radiate a mu
than the photosphere.
an absorbing atmosph
light of longer wave-
effect would be seen i
were at the same lev
the difficulty it is only
measures to a single co
tion, comprising light

The spectroheliogra
plishing this. It is em
spot and the surroundi
sponding to the chang
disk. In making these
on any of the spectral li
preferably in the yello
neous light will be leas
of the darkness of the
about six times as long

photograph of equal intensity, it is desirable to decreas intensity of the photospheric light by a dark glass, placed the slit, but so arranged as not to reduce the light fro sun-spot. In this way the spot and photospheric light c compared from day to day, by means of photometric m urements. The same method can be employed to me the level of the flocculi. Such work is now in progress a Solar Observatory, in conjunction with the other inves tions already mentioned. Since the level of a spot affect its temperature, and therefore its spectrum, an att will be made to correlate this work, not only with deter tions of the spot's motion, but also with the spectros observations described in chap. xvii.

These few examples may suffice to give an idea o character of the work done with the spectroheliograph c Snow telescope. The vertical motion of the calcium v in the flocculi; the manner in which it flows horizon over sun-spots; the relationship, in point of developme flocculi to spots; and other similar matters, are also st systematically. It may also be added that the area o flocculi is measured on each day's plates, since it serves index to the Sun's activity, which may prove important considered in its bearing on possible variations of the radiation and their effect on terrestrial phenomena.

CH

A STU

It has already beer
though apparently much
reality, brilliantly lumi
pear dark merely by c
brilliancy has given ris
most recent theories ha
much hotter than othe
photospheric clouds, du
from the Sun's interior,
Lockyer's arguments i
terrestrial elements are
of the stars is based up
maxima the spots are to
trial elements to exist i
upon a long series of
spectra of sun-spots.
solar spectrum in the f
strengthened or widene
unchanged (Plate LXX
intensities are thus al
indeed, if the fainter li
thousands. Lockyer's
every clear day, the "
spectra of spots then
seemed to indicate that
lines represent known s
many of these give plac
uted to unknown substa

elements at the high temperature assumed to be char
istic of periods of greatest solar activity. Some of his
papers favor the view that sun-spots[1] possess a lower
perature than would thus be indicated, and he may the
have decided to abandon the conclusions based on his e
spectroscopic observations.

In spite of these results, and of all the theories
attribute high temperature to sun-spots, the more cor
opinion has been that they are regions of reduced tem
ture. This view has been based partly upon their decr
brightness, as compared with the photosphere, and
upon the presence in their spectra of certain bands w
though unidentified, were supposed to represent mole
that cannot exist at the high temperature of the Sun.
rate knowledge of these bands, however, was almost en
lacking, on account of their faintness and the extreme
culty of observing them visually.

It seemed probable that progress in this departme
solar research might be expected to result from the suc
ful application of photography to the study of spot sp
Experiments made with this object in view at the Ken
Observatory showed some of the principal widened
but failed to give the details needed for satisfactory
These results were surpassed by photographs made by Y
with the 23-inch Princeton refractor, but here also the
of more powerful instrumental means seemed to be appe
The Kenwood experiments were continued with the 40
Yerkes telescope, and some of the "band lines," first obs
visually by Maunder, were photographed, in addition to
of the widened lines. However, there was reason to be
that much better results could be obtained with the aic
long-focus grating spectrograph, capable of photograp

[1] Because of the great strength of the titanium lines in *Arcturus*.

the spectrum on a large
deferred until it could l
and a powerful Littrow

This spectrograph is
the Sun is formed on a sl
a 6-inch collimating obj
renders the rays paralle
a plane grating, *g*, wh
spectra. Light from a p
to the objective, *o*, whic

Path of R

a photographic plate, *p*
order to form the imag
slightly inclined backw

This instrument, as
scope, is shown in Plate
trograph stands immed
section of it can be rota
to the prism-train of
spectrograph is to be us
the concave telescope m
cient distance to transf
heliograph slit to the sp
the mirror backward th
is raised to the proper
spot is brought exactly
motion electric motors,
and controlled from a p

In photographing th

excluded from the spectrograph except that which comes
the umbra. This is done by covering all of the slit e
a small portion at the center. The dispersion of the se
or third order of the grating is usually employed. After
exposure has been completed, the center of the slit is co
and light from the photosphere admitted on each side.
gives a narrow photograph of the spot spectrum bet
two strips of solar spectra (Fig. 1, Plate LXXIV).

Casual examination of the spot spectra thus record
sufficient to show that the problem of interpreting the
not a simple one. If we consider, for example, the lin
some single element represented in the spot, we find that
are not all affected alike. Some are greatly strengthe
or perhaps attended by broad, faint wings. The former
is so very pronounced, in certain cases, that lines w
invisible in the solar spectrum are among the most co
cuous of the spot lines. Some of the solar lines, on the
trary, are greatly weakened, or entirely absent in the
spectrum. Finally, there are many spot lines of uncha
intensity. Examples of most of these phenomena are i
trated in Plates LXXIV and LXXVI.

In order to interpret such results, it is necessary to
recourse to laboratory experiments. It might be supp
that the required knowledge of terrestrial spectra woul
available in the literature of spectroscopy. This, how
is not the case. It is true that the lines in the spect
most of the elements have been measured, and many ex
ments have been made on the changes in spectra prod
by varying the conditions under which the vapors emit
radiations. It usually happens, however, when one atte
to apply published results to the interpretation of
phenomena, that the data required for the solution o
particular problem in hand are lacking. Pressure,
example, is known to displace spectral lines toward the

and the actual shifts of
ments have been measur
centage of the total nu
substances, and the shi
under investigation are
The same may be said of
It has long been know
increases the relative b
that of others, and is wi
trum. Indeed, it was ev
which are prominent at
conspicuous lines of spo
so few and scattered th
upon them. Moreover,
these changes of relativ
by temperature alone.
variations of spectra ha
charges, where causes
greater influence than
of the spectra. Exampl
that the study of solar
on effectively without a
ments, planned with sp
particular problem und

For this reason muc
ment of the Solar Obse
laboratory facilities. I
spectroscopic laboratory
clude a considerable nu
be examined under var
sure, etc., but also to a
appeal to one or the otl
the delays ordinarily e
specially set up for a c

plan the apparatus must be always ready, needing only turning-on of an electric current, or the adjustment mirror, to bring it into action. It is not so much a que of the saving of time, which the provision of these m undoubtedly offers, as it is of the greatly increased effici of the working programme thus rendered possible. immediate imitation in the laboratory, under experim conditions subject to easy trial, of solar and stellar nomena, not only tends to clear up obscure points, but pares the way for the development along logical lin the train of reasoning started by the astronomical v Questions are constantly arising which, if partially or wh answered by suitable laboratory experiments, may m in an important way the daily programme of astronon observations.

The arrangement of the apparatus in the spectros laboratory of the Yerkes Observatory has already described (p. 107). At the Solar Observatory an impr plan has been adopted. Instead of a circular wooden t an annular concrete pier is employed, giving space on inner wall for the various switches used to control the rent supplied to the different sources, and also permit the observer to inspect any light-source from the direc of the plane mirror at the center of the pier. Instead single plane mirror, two are provided, capable of rota independently of one another about the same vertical When the Littrow spectrograph is used to photograph spectrum of any of the light-sources, only the lower p mirror is in action. By setting this at the proper a light from any source on the annular pier can be se a concave mirror (seen near the middle of Plate LX which forms an image on the slit of the Littrow spe graph. If low dispersion, rather than high dispersio required, a one-prism quartz spectrograph is used. Ag

for the special study of
ing power, particularly
an echelon spectroscope
mirror is tipped back
light to the upper plan
the slit of one of these
quartz spectrograph m
mirror, while the echel
right, near the end of t
which is ordinarily emp
trograph used with the
which carries the slit a
shown on the pier in t

The following appa
first instrument on the
used for the study of t
of a magnetic field in
components. For exam
between iron terminals
when observed with the
spectroscope. If, howe
poles of a powerful mag
is to break each line up
take us too far away fr
the theoretical questio
It may be said, howeve
lines behave similarly
field, we can tell whet
together in the Sun. I
magnetic phenomena i
has not revealed any evi
of affecting the appeara
less, the method provid
certain groups of lines,

to one another that we should expect them always to be alike when observed in the Sun or stars.

In the illustration a mercury tube is suspended bet the poles of the magnet and connected by heavy pre tubing with a duplex vacuum pump, by which the pre of the mercury vapor, illuminated by the discharge c induction coil, can be reduced as desired. The cu required for the magnet is supplied from a large stc battery in an adjoining building. This battery is the cipal source of current for most of the apparatus on annular pier; an alternating current, required for ce experiments, is obtained from a generator in the power-h

It would be tedious to describe in detail all of the a ratus. It includes arrangements for studying the s spectra of metals in air and in liquids; arc spectra in g at high or low pressure; flame spectra, for which a Bu burner and an oxyhydrogen blow-pipe are required; vac tube spectra; etc. A small electric furnace permits the nomena of anomalous dispersion to be observed in the va of sodium and other metals which melt at low temperat The auxiliary apparatus includes a special pump capab compressing gases up to pressures of three thousand po to the square inch; an induction coil, giving a 16- spark; X-ray apparatus for the study of the effect of X- on the radiation of gases and vapors; a small heliosta supply sunlight; etc. All of the work on the solar ir is done in the Snow telescope house, but sunlight is quently required in the laboratory, to give a solar spec for comparison with the laboratory spectra.

Let us now return to the problem of explaining strengthening and weakening of the solar lines in sun- spectra. As already remarked, there was reason to sus that reduced temperature might be the effective caus these changes. Accordingly, the spectrum of iron

photographed by Gale
with a large current (1
current (2 amperes).
that are strengthened in
the 2-ampere arc, while
in spots are also weake
majority of the lines sh
is also the case with
Similar results were obt
mium, manganese, and

The next question w
vapors in the 2-ampere
30-ampere arc. This is
on account of various
appear at first sight.
compare the spectrum
from the arc with that
carbon poles. As the o
much cooler than the c
temperature should be a
in the most complete n
the current. In other
of the arc to the cooler
sities of the lines of t
observed in comparing
spectrum, were found.
modified relative intensi
result of a local reducti

However, it is not
phenomena in the arc n
istic radiations of the va
so much on this subjec
ascribe the observed lin
conditions of the arc,

changes can have any influence upon them. Thus results so far obtained would not be accepted as proof the spot vapors are at a lower temperature than the c sponding vapors in the Sun's reversing layer. It rema to be seen whether simple reduction of temperature, u conditions which excluded any possible influence of elect effects, would be competent to change the relative intens of the lines in the same way as passage from the core t flame of the arc had done.

The simplest way of testing this was to inclose the r in question within a carbon or graphite tube (chosen bec of its power to withstand very high temperatures), ar heat this tube by a powerful electric arc playing on its c walls. Under these conditions, since the vapors are observed within the electric arc, but are separated from flame of the arc by the walls of the carbon tube, it sh be possible to determine the effect of change of tempera on the relative intensities of the lines.

As the dynamo on Mount Wilson was not adequat supply the electric power (50 kilowatts) desired for work, the furnace was erected in the Pasadena labora of the Solar Observatory. As in an electric furnace by Moissan, the arc was produced between two large ca poles, in a box with carbon walls, surrounded by a large of magnesite, inclosed in a sheet-iron case. Running l tudinally through the carbon box, and between the pol the arc, a carbon tube containing the metal was placed. tube extended out through the walls of the furnace, so light from the hot vapors seen through its open end c be focused on the slit of a Littrow spectrograph of 18 focal length (similar to the one used with the Snow teles in photographing spot spectra).

With this furnace it did not prove to be possibl vaporize titanium and vanadium, but the test was mad

chromium and iron. T
these metals were foun
the flame of the arc.
strengthened in passing
are also strengthened in
electric furnace. More
the carbon tube in the
still glowing vapors con
the lines strengthened i

But the proof is not
ties available, it was not
the furnace through a s
changes in the relative i
might be argued that th
the arc of some lines, a
are due to electrical ph
perature. The *inferenc*
ture was the deciding
intensities of the lines,
the arc and to the furn
excluded in the latter.
furnish an absolute *pro*
through increase in the
duce spectra in which t
the same as in the case
in progress with this en

Fortunately, howeve
mation to which we m
oxygen exists in the pre
titanium. Now, it is w
under conditions of ver
metallic vapors in sun-
vapors outside of spots,
be sufficient to permit t

with some of the metals present. Titanium oxide, in ular, is capable of resisting a very high temperature, would immediately dissociate an oxide of iron. Is the evidence, then, that titanium oxide exists in sun-spots

Thanks to the excellent photographs of spot spect tained with the aid of the Snow telescope, this ques easily answered. Titanium oxide gives a very charac *fluted* spectrum, consisting of bands in which the nu lines lie closer and closer together until they termi definite "heads." Fig. 2, Plate LXXIV, shows s these titanium oxide flutings in the extreme red end spectrum, as photographed (on specially sensitized in the outer flame of the electric arc. The photog a *negative;* i. e., the lines which are bright in the shown dark, to facilitate comparison with the dar in the photograph of the spot spectrum, shown just the titanium oxide spectrum. It will be seen at a that each of the heads of the fluting is represen the spot, and that a great number of the fine lines make up the fluting also agree in position with corre ing spot lines. The spot spectrum contains man not represented in the arc, which are due to sub other than titanium oxide. The arc spectrum also c a few lines due to impurities, which are not present spot. Nevertheless, the general agreement is so perfe the presence of the titanium oxide bands in spot cannot be doubted. Several other bands belonging same substance are also represented in our photogra spot spectra.

The identification of these bands by Adams woul to leave no doubt as to the reduced temperature of t vapors. The objection might be made, it is true, tha question exists as to whether these bands are actually the oxide, since there is some reason to suppose that ti

itself is capable of proc
which gives them rise
which produces the line
experiments the fluting
as the temperature is r
is broken up at high te
ings from the spectrun
Moreover, Fowler, in I
green flutings in the
the spot spectrum to
Olmsted, on Mount W
flutings with those of c

It therefore appears
stitute the umbra of a
sponding vapors in ot
readily account for th
lines and for the compa
cause of such a reducti
mined. Knowledge of
spot vapors at once per
spot theories which pos
attack the question of
intelligent manner.

In order to facilita
spots, a preliminary ph
has been issued by the
twenty-six sections, ea
units of the spectrum, t
length 4600 to wave-len
negatives, Ellerman ph
plate, moved up and d
lines) during the exposu
spot spectrum, and ren
the relative intensities c

notice. Beside each strip of the spot spectrum the no
solar spectrum is given for comparison (Plate LXXVI)

The information derived, as explained above, from s
and laboratory investigations applies not only to the
If, by cooling in some degree the vapors lying with
limited area on the solar surface, the spectrum is cha
in the manner illustrated in sun-spots, it should follow
if the entire Sun, or a star like the Sun, were cooled in
same degree, its spectrum would resemble that of a sun-s
Our ideas of stellar evolution are based on the belief
stars exist in all stages of development and differing gre
in temperature. If our inference be correct, we should
among the stars which have passed by continued coo
beyond the solar stage, some in whose spectra spot l
appear. The next chapter explains how this test has
applied.

C

STEL

THE advantages of
work have been menti
of the Sun the amount
that grating spectrosc
used without difficulty
weakened by dispersio
bered that the light en
one-thousandth of an i
trum many feet in len
only a small amount o
reason the spectroscop
inferior in dispersion t
interpretation of stell
since several closely a
one. If, then, we are
stellar lines, in order,
apparent analogy wit
studying stellar spect
used for solar observat

A difficulty which
has an important beari
required for such work
trum of a star to goo
could be obtained wit
sions, supplied with a p
reasons, photographic
in stellar spectroscopy,
of a few of the brighte

spectra cannot be seen, on account of the faintness of light. In the second place, the unsteadiness of the im due to atmospheric disturbances, causes the extremely na spectrum to flicker so seriously as to prevent any ref work. This flickering, however, has no effect upon the ph graphic plate, which merely sums up all of the ligh receives during the exposure. Moreover, by prolonging exposure, a spectrum too faint to be seen can be reco photographically. In all modern work of precision, th fore, photographs of stellar spectra are substituted for vi observations.

But the photographic plate has a granular structure, to the fact that it is made up of silver grains, which ca separately distinguished with a microscope. On accou this granular structure of the plate the details of the in are imperfectly recorded, so that no advantage results f the use of high powers when examining the plate. If visual image could be well seen at the spectroscope increase of magnification (attained by the use of a suit eye-piece) would separate all lines within the resolving p of the prisms or grating. On the photographic plate, l ever, the images of these lines may lie so close together they appear as one, and cannot be separated by magnifica What is needed, in order to realize photographically the resolving power of the prisms or grating employed, is a s troscope of such length that the closest lines that coul distinguished visually are so far separated as to be indep ently recorded, in spite of the effect of the silver grains.

The powerful grating spectrograph used by Rowlan his study of the solar spectrum has a focal length of 21 Photographs made with a spectrograph of this size s nearly all the lines that can be separately distinguishe visual observations with the same instrument. Obvious would be out of the question to attach such a spectrogr

or even an equally pow
type, to the end of a
the very high dispe
stars, exposures prolo
changes, or the slight
exposure, would shift
and thus destroy, by
advantages afforded b

Such instruments a
Potsdam Astrophysica
of the Lick Observato
Yerkes Observatory, g
stellar spectra, from t
of stars in the line of
cision. For most clas
hardly be surpassed.
of resolving power a
prevents them from se
Rowland in his studie
to be greatly desired t
stars, at least, be phot
ful as Rowland's. In
graph must be fixed i
tained at a constant te

To test the feasibi
spectrograph of high
used with a 60-inch r
spectrograph of 13 f
the Snow telescope.
triangular stone pier
house of the Snow tel
so constructed that t
it are very slight. Th
mounted so as to form

box containing water. An extremely delicate thermostat, c sisting of a bulb containing saturated ether vapor imme in the water, caused a column of mecury to make or b an electric circuit if the temperature of the water varie much as a hundredth of a degree. When the temperature by this amount, a relay turned on the current of two in descent lamps immersed in the liquid. The heating prod by the lamps raised the temperature, and the current then automatically cut off. The water was constantly sti by small propellers driven by an electric motor. In this the grating, which is, of course, the most sensitive part of apparatus, was kept at an almost perfectly constant temp ture throughout the exposure.

Arcturus, on account of its yellowish color and the cha ter of its spectrum, has long been considered to represe stage of stellar development somewhat advanced beyond of the Sun. As its spectral lines show its chemical c position to be practically the same as that of the Su reduction in temperature, due to cooling continued bey the solar stage, should, on the hypothesis developed in last chapter, cause its spectrum to resemble that of a spot. Accordingly, the spectrum of *Arcturus* was ph graphed with the Snow telescope and the grating spec graph.

Because of the great dispersion, an exposure of five ho which was all that could be given on a single night, entirely insufficient. In fact, an exposure continued for nights in succession, and aggregating twenty-three ho was required. During all this time it was essential that temperature of the grating remain practically constant, that none of the parts of the spectrograph be displace any cause. For this reason the observer did not enter constant-temperature room after the exposure was sta but merely brought the star to the slit of the spectrog

each night, and main
image reflected from t
deviations in its posit
from night to night, u

In these first exper
were not fairly tested,
the apparatus. The
work, and is not well a
over, work in progres
vibration of the piers,
Nevertheless, the resul
to show that this me
the 60-inch reflector,
essentially inferior to
60-inch reflector will
as the Snow telescope
dispersion, will be dec
spectrum of *Arcturu*
grating used for the p
subsequent experiment
large prisms can be us
grating for stellar spe
dispersion, will be still
60-inch reflector, the d
to make the scale of th
Rowland's solar spectr

Plate LXXVII sho
thus photographed, in c
Barring some exceptio
be noticed that the sp
more closely than it d

[1] In comparing these spectr
to adjoining (unaffected) lines
absolute intensity in the photog
precaution be observed.

of the imperfections of the *Arcturus* photograph, mar the lines are shown with less contrast than they would exhibit in a really good negative. However, the illustr should be sufficient to indicate the important bearing of spectra on the question of stellar temperatures.

The earliest classification of stellar spectra was th Secchi, who distinguished four principal types: I, sp of white and bluish-white stars, like *Sirius*, which co broad and strong hydrogen and calcium lines, and bu lines, narrow and comparatively faint, of other elements spectra of yellowish-white stars, like the Sun; III, sp of red stars, containing a very characteristic series of b not identified by Secchi; IV, spectra of another class o stars, containing the strongly marked bands of carbon. bands in the spectra of stars of Secchi's third type finally identified by Fowler, who showed that they are to titanium oxide. In view of the presence of these bands in spot spectra (Fig. 2, Plate LXXIV), it bec interesting to inquire whether the lines in stellar spect this type also resemble those in sun-spots.

The brilliant red star *Betelgeuze* (*α Orionis*) which sents so striking a contrast with the bluish star *Rig* the constellation of *Orion*, is a good representative o third type. It was accordingly selected to test the ques A dense flint glass prism belonging to the 5-foot spectroh graph was substituted for the grating in the large st spectrograph of the Snow telescope, and the thermostat modified so as to control the temperature of the air surro ing the prism. In this way the spectrum of *α Orionis* photographed by Adams, with a total exposure of seven h on two consecutive nights. The work was done during rainy season, and clouds, followed by continuous bad wea cut short the exposure on the second night, and prevente observations from being continued. The plate, while

strong enough to be of
sufficiently good to serve
parison. It was found t
stronger than in the Sun,
ened in spots are much
Orionis than lines unaffe
strengthening is much m
than in the spots thems
temperature is lower. A
conspicuous feature of th
present in sun-spots, the
complete. More detaile
reveal various discrepan
composition or physical
said, in general, that the
sun-spots and those of th
cate that the same cause i
of many lines in both inst
work indicates, is to be r

Thus we have been
phenomena of our typica
interpretation by laborat
tion of the general quest
now inquire whether o
applied to determine the
the possibility of measu
stars.

The early experiment
lack of suitable apparat
degrees of heat which re
Boys was no more succ
trated the stellar radiat
micrometer, which woul
temperature. With the

heat received by his telescope mirror from the full Moon c be detected. Yet the brightest stars produced no ce effect. As the result of this work, Boys was convinced no star sends us as much heat as would be received fr candle at a distance of 1.7 miles, if there were no at pheric absorption.

The subject of stellar heat was investigated by E Nichols at the Yerkes Observatory, in 1898 and 1900. radiometer employed as the heat-measuring apparatus sisted of two circular vanes of mica, each about one-tw of an inch in diameter, attached to the opposite ends delicate cross-arm of drawn glass, cemented to a whip of drawn glass about one and one-quarter inches long. Tc lower end of this system a minute mirror, made by silve a fragment of very thin microscope cover-glass, was attac and the whole was suspended by a very fine quartz fibe a vacuum chamber. This radiometer was mounted on a in the coelostat room of the Yerkes Observatory. A coel reflected the starlight to a 24-inch mirror of 8 feet l length, which concentrated the stellar rays upon one of vanes, after entering the radiometer case through a wir of fluorite, which is very transparent to heat radiations. observing a scale reflected in the small mirror attache the radiometer suspension, the deflection of the vane, w indicated the heating effect of the stellar rays, coulc measured. In this way it was found that *Arcturus* send about as much heat as would be received from a candl miles away, if there were no absorption in the atmospl *Vega* has less than half the thermal intensity of *Arctur*

The extraordinary sensitiveness of the apparatus empl may be illustrated by some observations of a candle 2 feet from the observatory. Heat from this candle, w concentrated on the radiometer vane of the 24-inch mi gave a deflection of about sixty-two scale divisions. On

occasion the assistant
his head in front of it
uncovering the flame.
radiation of his face, at
five scale divisions!
number of candles in a
could be determined fr
urements of their total

As *Arcturus* and *Ve*
eye, the greater heat r
that it sends out a large
If neither star possesse
then be concluded that
much larger in angular
as to be fully as bright
twice as much heat.
absorbing atmosphere o
than that of stars lik
hold. We are therefo
these experiments as t
stars.

Lockyer has recently
temperatures of stars
photographed under si
which of two stars send
light. In accordance w
of violet light emitted
temperature rises. By
intensity in the spectru
to determine its tempe
already remarked, no ab
upon a test of this kind.
appear red in color, no r
pared with stars whose a

we have here just such a condition of things as we obser
the setting Sun, which appears red simply because the v
rays are more highly absorbed by our atmosphere thar
red rays. It seems to be true that the older and cooler
have denser atmospheres than the younger and hotter
It is thus probable that the stars whose spectra contai
greater proportion of red light actually are cooler than t
in which the violet light is relatively stronger. But
fact remains that we are not warranted in basing determ
tions of stellar temperatures on measurements whic
obviously depend upon the effect of atmospheres of unk
density. We will return to this question of stellar tem
tures in a further consideration of the classification of
(chap. xx).

CI

THE NE

In the preceding ch
stellar evolution depend
knowledge we can obta
star. We have also ex
solar, stellar and labo
advantage of the opport
Sun-spot spectra to illu
various means of resear
general considerations
examine some of the p
offered to account for
systems.

Passing over the im
conclusions drawn by I
tions, we reach the nebu
brated explanation of th
nated the world's thoug
The eminence of its a
great work on celestia
acceptance of his ideas
form and without the
The greatest physicists
century have given tl
nebular hypothesis, and
Sun have been based u
of recent destructive cr
of Laplace's speculatio
ing to account, by a

observed phenomena. Nor must we overlook his re that the hypothesis was presented "with the distrust should be inspired by everything that is not the res observation or calculation." The widespread and favc influence exerted by the hypothesis on the intellectua of the nineteenth century cannot be destroyed by r developments. In the same way, the beneficial effe Darwin's work on organic evolution would remain, ev the hypothesis of natural selection were forced from its by that of mutation.

As the original statement of the nebular hypothe not easily accessible to every reader, it seems desirat include here a free translation of Note VII, at the e Laplace's *Exposition du système du monde.* A few graphs, dealing with more technical details, are omittec all of the essential features are retained.

In seeking to trace the cause of the original motions c planetary systems, the following five phenomena, enumerat the last chapter (of Laplace's book), are available: the motic the planets in the same direction and nearly in the same plan motions of the satellites in the same direction as the planets motions of rotation of these different bodies and of the Sun i same direction as their orbital motions, and in but slightly dif planes; the small eccentricity of the orbits of planets and sate finally, the great eccentricity of comets' orbits, as though inclination had been left to chance.

So far as I am aware, Buffon is the only one who has endea since the discovery of the true system of the world, to trac origin of the planets and their satellites. He supposes t comet, falling upon the Sun, drove from it a torrent of m which reunited at a distance in several globes, varying in siz in distance from the Sun; these globes, having become opaqu solid by cooling, are the planets and their satellites.

Laplace then goes on to show that, although this hy esis might account for the first of the five phenoi

mentioned above, the
it. In seeking to disc
follows:

Whatever be its natu
motions of the planets, it
and, in view of the prod
could only have been a flu
them a nearly circular moti
the fluid must have surrou
consideration of planetary
the result of excessive he
beyond the orbits of all th
cessive steps to its present

In the assumed primi
those nebulae which are sl
a more or less brilliant n
in condensing toward the
a star. If, by analogy, we
in this manner, we may i
preceded by other states,
and more diffuse, the nucl
going back as far as pos
diffuse that its existence c

Philosophical observe
peculiar distribution of
Mitchel has remarked on
Pleiades, for example, co
narrow limits which incl
hence concluded that this
heavens, are the effects of
nature. These groups are
of nebulae having several
lar matter were continually
would ultimately form a g
The condensation of nebul
stars lying very close toge
like the double stars whos

But how has the solar
rotation and of revolution

bodies had penetrated deeply into this atmosphere, its resi would have caused them to fall upon the Sun. We may thu jecture that the planets were formed at its successive limits, condensation of zones of vapors which the Sun, in cooling have abandoned in the plane of its equator.

Let us recall the results given in a preceding chapter atmosphere of the Sun could not have extended out indefi Its limit was the point where the centrifugal force, due motion of rotation, balanced the attraction of gravitation. N cooling contracted the atmosphere and condensed at the sur the Sun the molecules lying near it, the motion of rotation a ated. For, from the law of areas, the sum of the areas des by the radius vector of each molecule of the Sun and of its phere, when projected on the plane of its equator, being the same, the rotation must be more rapid when these mo approach the center of the Sun. The centrifugal force due motion thus becoming greater, the point where it equals the is nearer the Sun. If we then adopt the natural suppositio the atmosphere extended, at some period, to an extreme li must have left behind, in cooling, the molecules situated limit and at the successive limits produced by the acceleral the Sun's rotation. These abandoned molecules must hav tinued to revolve around the Sun, since their centrifugal for balanced by their weight. But since this equilibrium d obtain in the case of the atmospheric molecules in higher lat their weight caused them to approach the atmosphere as i densed, and they did not cease to belong to it until this brought them to the equator.

Let us now consider the zones of vapor successively left b To all appearances these zones should form, by their conden and the mutual attraction of their molecules, various con rings of vapor revolving around the Sun. The mutual fric the molecules of each ring should have accelerated som retarded others, until they had all acquired the same a velocity. Thus the linear velocities of the molecules farthes the center of the Sun must have been the greatest. The foll cause would also contribute toward the production of this diff of velocity. The molecules farthest from the Sun, which, th the effects of cooling and condensation, came together to fo outer part of the ring, always described areas proportional

time, since the central forc
directed toward the Sun.
the velocity increase as th
that the same cause mus
molecules which moved ou

If all the molecules o
without separating, they
But the uniformity which
the ring, and in their ra
phenomenon extremely ra
single example of it, that
cases each ring of vapor
which, having only slightl
at the same distance aro
assumed a spheroidal form
ing in direction with tha
molecules had smaller lin
they thus formed as many
of them had possessed suff
others successively togethe
would thus have been tra
vapor, revolving about the
sponding to that of its r
most common one. Nev
example of the first case in
Jupiter and *Mars;* unless
that they originally forme
explosion into several part

Now, if we follow the
have produced in the vap
just pictured, we shall wit
of a nucleus which contin
of the atmosphere surroun
resembles the Sun in its
must thus have produced,
phenomena similar to thos
and satellites revolving a
motion of rotation, and t
selves. The symmetrical
center and in the plane o

hypothesis, and would be inexplicable without it. These seem to me ever-present proofs of the original extensi *Saturn's* atmosphere and of its successive retreats. Thu singular phenomena of the slight eccentricity of the orbits planets and satellites, the small inclination of these orbits solar equator, the identity in direction of the motions of ro and revolution of all these bodies with that of the solar rot flow from our hypothesis and give it great probability.

If the solar system had been formed with perfect regu the orbits of the bodies which compose it would have been whose planes, like those of the various equators and rings, have coincided with the plane of the solar equator. But it n conceived that the endless varieties which must have existed temperature and density of the various parts of these great n produced the eccentricity of their orbits and the deviation of motions from the plane of this equator.

In our hypothesis, comets are strangers to the planetary s In considering them, as we have done, to be small nebulae w ing from system to system, and formed by the condensat nebular matter distributed with such profusion throughou universe, we perceive that, when they arrive in the regi space where the solar attraction is predominant, it forces to describe elliptical and hyperbolic orbits. But their m being equally possible in all directions, they must move indiffe in all directions and at all inclinations to the ecliptic; whic agreement with observation. Thus the condensation of n matter, by which we have just explained the motions of ro and revolution of the planets and satellites in the same dir and in planes differing but slightly, also explains why the m of comets do not agree with this general law.

Laplace, after discussing the great eccentricity of co orbits, as bearing on the nebular hypothesis, continu follows:

If certain comets entered the atmospheres of the Su planets during the formative period they must have fallen these bodies, after pursuing spiral paths. The result of the would be to cause the planes of the orbits and the equators planets to deviate from the solar equator.

If in the zones left beh
molecules too volatile to
planets, they must have co
would thus give rise to suc
light, without offering app
of the planetary system, e
because their motion is ver
which they encounter.

A close examination of
still further to the proba
fluidity of the planets is cl
figure, in conformity with
molecules; furthermore, it
the regular diminution of
This condition of original fl
cal phenomena, should sh
history. But, to perceiv
account the immense vari
restrial substances mingle
reduction of temperature
themselves. It is also nec
that this fall of temperatu
within the Earth and upo
constitution and the press
in the bodies which it h
should be given to violen
eruptions, which must hav
larity of these changes. (
which unites it to astronor
in many particulars.

Although the nebula
acceptance, objections a
at various times during
cisms of Babinet and F
ments of Faye, who con
from the ring-system of
site direction. Laplace
were to form the plan

outer edge traveling faster than the inner one. This w
have involved forward rotation of the planets, as now obse
But such a condition of things could not have occurred–
rings, split asunder by the forces acting upon them,
have followed Kepler's laws, which would require the i
edge to move the faster. The rings of *Saturn*, held u
Laplace as a striking illustration of his views, were sh
by Maxwell in 1859 to be composed of small bodies
meteorites. This was the result of a mathematical de
stration that the rings, if solid, would fly to pieces. It
confirmed by Keeler, in 1895, by one of the most beau
applications of the spectroscope ever made. Accordin
Doppler's principle, the position of a line in the spec
of a moving body depends upon the velocity of the
tion. This is true, even when the light is reflected
the surface of the moving body, after being received
the Sun. If the inner edge of *Saturn's* ring is mo
faster than the outer edge, the lines in the spectrum o
ring should be increasingly bent toward the violet (o
approaching side of the planet) or toward the red
the receding side), in passing from the outer toward
inner edge. Keeler's photograph of *Saturn's* spec
shows this to be the case. Thus we have certain proof
Saturn's rings are made up of meteorites, each moving a
velocity a satellite would have at the same distance fro
planet.

In spite of these and kindred objections, the ne
hypothesis, at least in its general outlines, retained its
manding position until subjected to a searching test i
tuted by Chamberlin and Moulton. The principal argu
brought together in Moulton's paper, entitled "An Att
to Test the Nebular Hypothesis by an Appeal to the La
Dynamics,"[1] and in the discussion of the question in Vol

[1] *Astrophysical Journal*, Vol. XI (1900), p. 103.

II of Chamberlin and
marized below.

In the paper just r
lar hypothesis in muc
employed. In other
complete as possible,
might consist of a ga
Darwin had proved m
gases may be fulfilled
discussion, moreover, d
a very high temperatu
has shown that the pre
for as a result of the c
low temperature. Fin
not limited to the aba
to include possible d
separated portions havi
satellites.

The fact that the re
those of *Uranus* and N
while the planes of the
are almost perpendicul
is an old argument aga
the former difficulty c
inclination of the orbit
tune seems to be directl
second place, the masse
densities of the rings
formed, are shown to b
the hypothesis would l
satellite revolves about
the planet's rotation, w
velocity to be much le
Darwin has shown that

retarded the rotation of *Mars*, without affecting the satel motion. But Moulton points out that the inner edg *Saturn's* ring completes a revolution in about half the of *Saturn's* rotation period. At this great distance the Sun, the very small tides could not have retarded ficiently the rotation period of *Saturn*, unless they been operating several thousand times as long as the Ma tides. An attempt to ascribe the effect to the satellit *Saturn* proves equally futile.

Moulton next endeavors to answer the question wh the supposed initial conditions could have developed int existing system. We know that the molecules of a ga moving about at velocities which increase with the tem ture. Near the surface of the original Laplacian nebul velocities of the molecules, in the case of such light elen as hydrogen, would be so great that the molecules w overcome the power of gravitation and be dispersed in s It would, therefore, be difficult to account for the abun supplies of this gas now observed on the Sun. A stro objection is afforded through the application of these ciples to the planets. It is easy to calculate, through known velocities of gaseous molecules and the masses of planets, the power of each planet to retain an atmosp It is also possible to determine with the spectroscope wh atmospheres exist on the planets. Working in this Moulton shows the improbability that the diffuse Earth-M ring, with its low power of attraction, could have held ar the atmospheric gases or water vapor, when such concentr bodies as the Moon and *Mercury* are unable at the pr time to hold atmospheres.

As we know the masses of the Sun and planets, average density of the original nebula, when it extende the orbit of *Neptune*, can be approximately calcul Moulton finds this to be about $\frac{1}{1\,9\,1\,0\,0\,0\,0\,0\,0\,0\,0}$ of that of w

In this extraordinarily
meteoroidal, it is show
behind continually and
would be impossible—
1869. Moulton thinks
could not have been de
thermore, even if a rin
utterly improbable tha
together into a planet.

Some of the above
question, but the final
It is a well-known prin
momentum of a syste
external forces is cons
defined by the sum of
particles by their veloc
center of the system.
lutely unchanged, whe
nebula occupying the
of planets revolving ar
tions in such a way as
hypothesis, Moulton o
moment of momentum

> When the nebula exte
> When the nebula exte
> When the nebula exte
> When the nebula exte
> In the system at prese

Thus, instead of
momentum is shown
In spite of the prec
hypothesis as much as
of the original syste
present solar system.

The papers of Chamberlin and Moulton contain o serious criticisms based upon the study of the momen momentum of the system, and raise various additional diff ties. Thus the attenuated state of the rock-forming substa of the Earth in the Earth-Moon ring would probably l resulted in their condensation into solid particles. Agai nebulae closely resembling the annulated solar nebula l yet been discovered. Without going further into details, without necessarily admitting the finality of all the a arguments, it can hardly be denied that Laplace's idea o development of the solar system must be reconstructe abandoned. It remains to be seen what can be substit for it. Two attempts in this direction will be described later chapter.

C

STELL

THE nebular hypoth
presents a picture of th
like our own. In test
theoretical investigatio
kinds, particularly of
the earlier stages of th
be remembered that
members of our solar
the distances of the sta
evolution we are concer
with the planets that m
less evident that the
independently, since th
in the formation of pla
tance in researches on
of which they may have

Herschel, whose min
lem of the structure of
individual members, th
evidences of growth a
the cloud forms, of irr
vast regions of the hea
rudimentary condition
a center, brought abou
shown in such a cloud b
line of nebular existenc
lae, in whose symmetric
condition as Laplace po

The mystery of the planetary nebulae still remains solved, but evidence is lacking that they represent a r advanced state than such irregular cloud masses as Great Nebula in *Orion*. Indeed, it must be admitted the accumulation of observations, principally through aid of photography, has rendered the problem of neb development more complex than it appeared to Sir Wil Herschel. Thousands of nebulae, entirely unknown to l have been brought to our knowledge through improvem in telescope design and the aid of the sensitive plate. T range in character from immense luminous tracts, suc are shown, intermingled with stars, in photographs of Milky Way, to the definite outlines and highly sugges structure of the spiral nebulae. Of all objects in the hea these latter most strongly suggest the operation of s process of development. But not a single object of this was known to Herschel, and even to this day their enorn distance from the Earth has prevented the detection of changes in form, which might point to the explanatio their origin.[1]

If we follow Herschel, and consider the simplest cas nebular development, we may suppose that through los heat by radiation a portion of a nebulous mass begin condense toward a center. Although still wholly gase and showing few points of difference from an ordinary neb we may regard such an object as representing the first pe in the life of a star. In the heart of the *Orion* nebula, F XXI, are four small stars, which constitute the well-kn *Trapezium*. Situated as they are in this enormous r of gas, it is not difficult to picture them as centers of densation, toward which the play of gravitational fo tends to concentrate the gases of the nebula. It m therefore be expected that stars in this early stage of gro

[1] See chap. xxi.

would show, through th
some evidence of relat
Now, this is precisely
strated. Not only the
stellation of *Orion*, are
the same gases that co
also partake of its moti
Adams have demonstr
these stars are actuall
panions situated in the
orbital velocities of th
seems probable that th
Nebula in *Orion* is exc
ance to motion within

Other examples of
surrounding masses o
this one will suffice for
consider what changes
the further developme
heat through radiatio

Fraunhofer was th
nineteenth century, to
simple method he em
prism over the object-g
through the skill and
effective agent for th
To Fraunhofer the diff
the spectra of differe
the work of Kirchh
the photographs made
Harvard College Obse
to the initiated. In
prism is mounted i
(refracting) telescope,

and made to follow its apparent motion by a driving-c
Under these conditions, each star-image in the field o
telescope is drawn out into a spectrum, which falls up
photographic plate at the focus. If the rate of the dri
clock were perfect, each of these spectra would be extre
narrow, and the "lines" which cross it might not be
ceptible. To give the spectra the necessary width,
prism is set with its refracting edge parallel to the di
motion, so that the spectra would drift on the photogra
plate, if the telescope were at rest, in a direction at
angles to their length. In making the photographs, the
of the driving-clock is slightly altered, so that the dri
the spectra during the exposure is just sufficient to give
the desired width. Without this drift, each "line" w
be merely a point in the spectrum. Plate LXXIX illust
how admirably the spectra of the various stars in the
are recorded, and brings before us evidence of the spe
diversity which is supposed to characterize the diff
stages of stellar growth.

As already indicated (chap. xviii), the spectra of
increase in complexity as the cooling process continues.
gaseous nebulae contain a few bright lines in their spe
the most conspicuous one of which belongs to a gas ("n
lum") not yet discovered on the Earth. The other nel
lines are due to hydrogen and helium. Those stars o
"*Orion* type" which appear to be earliest in order of d
opment contain no lines except those of hydrogen and hel
which are faint and very broad and diffuse. As these
are found in the gaseous nebulae, and as the relation
of these stars to surrounding nebulous matter is othe
apparent, there is every reason to believe that they repre
the earliest phase of stellar life. The stars of the *Trapez*
which have already been mentioned as organically relate
the Great Nebula of *Orion*, are of this type. "*Orion*" s

which appear to be son
of magnesium, silicon,
those of hydrogen and

Next in order of e
bluish-white, stars like
spectrum of *Sirius* is
hydrogen lines, associ
iron, sodium, magnesiu
gations of certain pairs
are in rapid rotation a
that stars like *Sirius* ar
specific gravity not exc
is exactly what would b
tion from a gaseous ne

It is well known t
that the condensation
the Sun originated m
amount of heat. Inde
accounted for by suppo
about 400 feet in the
paradoxical fact that a
radiation, will actually
gaseous condition, was
point is that the heat
sufficient to compensat
quently, the shrinking
purely gaseous. The
outer parts, which radi
tected from loss by ou
cooled to the point of c
metallic elements pres
clouds made up of min
terrestrial clouds, whic
water vapor.

When this point is reached, radiation must take p
mainly from the surface of the star. This would resul
very rapid surface cooling, were it not for convection
rents, which rise from the interior and supply the heat
by radiation. In the Sun we have strong evidence of
existence of such currents, which are represented by
bright filaments that constitute the granulated sur
(chap. xi), and by the minute flocculi illustrated in F
XXXIX. The darker spaces (pores) between the granulat
probably represent the cooler descending vapors. The de
vapors, which perhaps occupy these darker regions, appare
lie below the general photospheric level, for it has rece
been found at Mount Wilson that the spectrum of the S
disk, at points very near the limb, differs decidedly from
spectrum at the center. The hazy wings, which may be
on either side of many lines photographed at the Sun's
ter, and are still more conspicuous in sun-spots, are gre
reduced in intensity at the limb (Plate LXXXII).
would seem to indicate that at the center of the Sun we
looking down into the regions between the granulations,
level where the vapor is dense enough to produce the win
lines. Near the edge of the Sun, on the contrary, we
across the tops of the bright filaments, and therefore fai
receive light from the denser vapors below. The absorp
of the higher and cooler vapors should produce a change in
relative intensities of the lines such as takes place in
spots (p. 159), but in much smaller degree. Observa
shows this to be the case, but there is by no means a st
parallel between the two classes of phenomena, and ju
ment must be reserved for the present. One of the
steps will be to photograph the spectrum of a pore, i
minute an object can be separately observed. The in
tigation, when completely worked out, should furnis
searching criterion as to the validity of the hypothesi

reduced temperature in
phenomena in the Sun a

We have already see
the absorbing atmosphe
violet and ultra-violet ra
or reddish tinge into th
do not possess dense a
of this fact and of thei
spectra extend far into t

In passing from thes
which constitute the s
condensation is accompa
ing atmosphere similar
the ultra-violet, the al
appreciable as the sola
decrease of intensity, wl
region, is also manifest
spectrum, whereas the r
affected. The natural
a deficiency in blue li
solar class are yellowi
out that the Sun would
atmosphere were remov
color we have the decre
and the increasing str
become very numerous i
more so in the Sun.

As already remarked,
absorption prevents us f
stellar temperatures on
intensity in the spectr
upon comparisons of
lines, just as was done i
in chap. xvii. This me

to their temperature was applied by Lockyer many
ago. He found that the "enhanced lines," which
brightest in the spark spectrum of a metal, exist alo
certain stars. In other words, the arc lines of the
metal, which are strong at the lower temperature of the
and feeble or absent in the spark, are so much reduce
intensity in these stars as to be entirely invisible.

Lockyer's contention that these changes of relative i
sity afford a mode of classifying stellar spectra on a te
ature basis was denied by many spectroscopists, becau
the possibility that such changes might be produced in
by different electrical conditions rather than by differe
of temperature. The results obtained in our labor
imitation of sun-spot phenomena, however, seem to
the view that a temperature classification of stars, o
basis of the relative intensities of lines, is perfectly
sible. For in these experiments it was shown
when all electrical phenomena are excluded, a decrea
temperature of the radiating vapors is accompanied b
increase in intensity of the lines that are strengthene
sun-spots and in red stars. Since the spark lines are w
ened under the same conditions, and since conclusive
dence of comparatively low temperature is afforded by
presence in these spectra of flutings due to substances w
are broken up at the higher temperature of the Sun
temperature hypothesis may perhaps be taken as affordi
simple basis of classification. This statement is not
without some reservations, however, as indicated by
remarks at the end of this chapter, and by the discu
of Lockyer's meteoritic hypothesis in chap. xxi. More
since this classification takes no account of the possible
of mass and environment on spectral type, it is hardly l
to prove adequate.

Let us now consider the phenomena of declining

which have passed beyon
invisibility. It will be
orange or red in color an
classes, similar in appe
tinguishable with the ai
these classes (Secchi's
stars, such as the red
object in the southern h
The second class (Sec
representative. Indeed,
acter are but barely disc
great majority are to b
telescope.

In the spectroscope
more complicated than
growth. The broad lin
reduced in intensity in
the red stars. In fact, t
tain red stars given pla
case of variable stars,
irregular fluctuations.
the red stars, however,
dark bands or flutings.
of these bands lie towa
the intensity gradually
found by Fowler to be du
be broken up at the high
in the spectra of sun-spot
red stars of Secchi's four
with their sharply define
bands, as Plates LXXX
to carbon and cyanogen.
in the Sun, but in the fo
strongly developed.

The extensive investigations of Vogel and Dunér, visually, have given us much information regarding spectra of the red stars. However, the fourth-type stai so faint that only the bands in their spectra could be with the telescopes used by these investigators, and numerous dark lines were beyond observation. The light-grasping power of the Yerkes telescope rende photographic study of these spectra possible, with the r shown in Plates LXXXIII, LXXXIV, and LXXXV. the fourth-type stars are ranged in a series, the gr change of spectrum from star to star is well illustrated (F Plate LXXXIII). The carbon flutings become stronge stronger, until in a star like 152 *Schjellerup* they are so that they cut out a considerable portion of the light. I Sun, the Yerkes telescope shows the existence of a very layer of carbon vapor, lying in close contact with the p sphere. In the fourth-type stars we may suppose tha further process of condensation results in an incr development of carbon vapor, the absorption of which bec the characteristic feature of the spectrum.

Another important point brought out by this investig is the close relationship existing between the line spec third- and fourth-type stars. As will be seen by an e nation of Plate LXXXV, the line spectra of μ *Gemin* and 74 *Schjellerup* seem to be almost precisely identi certain regions. The presence of titanium oxide ban the one case, and the carbon flutings in the other, co cate the comparison of the line spectra in other reg though much is yet to be learned on this subject thr further study of these stars with spectrographs of the hi dispersion.

In view of the resemblance of the line spectra, it is cult to understand the diversity of the band spectra i two great classes of red stars. Among third-type sta

intermediate types of sp
and the most advanced r
thus seem, especially
between sun-spot and th
the Sun would result in
However, although no su
to exist in the transitio
seems possible that star
280 *Schjellerup* (see Pl
discovered. Should thi
rigorous test be found t
of the line spectra of th
tion whether a star like
into a fourth-type star
problem, which is one o
nected with the study
prominent place in the
Observatory.

Although the red st
nous stellar life, there re
which have been discov
bility. Hundreds of th
through spectroscopic
double or triple system
center of gravity. The
measurements of the os
move back and forth to
the star under observati
the earth in its orbital m
of the visible star whic
orbit necessarily implie
which may or may not
to be visible, it may no
in the most powerful t

the lines of the composite spectrum will appear double, in each orbital revolution of the pair. If only one st bright enough to give a spectrum, its lines will simply late to and fro.

Hitherto we have tacitly assumed, in harmony with rent views, that all stars are built on a single model, and each passes through the same stages of development i transition from the nebular condition to the solid state should be pointed out here, however, that many circumst warn us against implicit acceptance of such a law of formity. The assumption that a given type of spec represents a given stage of growth involves the idea tha chemical composition of all stars is essentially the same that the particular position of the star in the universe other conditions which may obtain in individual cases matters of no importance. While it is true that we strong reasons for belief in the universal distribution of of the chemical elements known on the Earth, and the versal operation of the law of gravitation, and of all laws which define terrestrial conditions, the assumption identically the same course is pursued by every st passing from its origin to its final decay is entirely warranted. We must be prepared to meet widely di conditions and to observe modifications in the proce development which are determined directly by such ditions.

Take the case of the *Pleiades*, for example (I LXXXVI). Here we have a group of stars entangle nebulosity, and moving together through the hea Every indication goes to show that this is an organic g whose members are of common origin. But the spect practically all of these stars, irrespective of size and br ness, are of Secchi's first type. How are we to believe widely different masses will pass through their evolut

steps with equal rapidit
members are undoubte
matters. We invariabl
system, which might h
because of its smaller s
larger companion is m
Huggins argues, howe
possessed by stars of la
in spectral type. Thu
farther advanced in sp
highly condensed star.
early steps in evoluti
gravity at the surface, c
ture in passing outwa
currents less violent th
star were hot enough,
ficiently cool, with res
show itself by absorpti
would lie lower in the
be so nearly that of th
would not appear in th

Schuster, who has
sizing the elements of
formity, nevertheless b
represent stages in the
he does not maintain t
series of changes, he a
course of development l
tant modifications may
of development which l

(1) Helium or *Ori*
(2) Hydrogen or *S*
(3) Calcium or *Pr*
(4) Solar or *Capel*

In describing the process of condensation, Schuster po out that the expansion caused by the rising temperatu the gaseous bodies must at first result in the rejectio helium, hydrogen, and other light gases, on the supposi that the gravitation is not sufficient to retain them. T light gases will thus be left to constitute diffuse nebu masses, as illustrated by the gaseous nebulae, particul by the nebulous regions in such a group as the *Plei* In the process of time, however, the star will have conde sufficiently to retain hydrogen and helium, and these g will then begin to diffuse into the interior, where they be absorbed at a rate which depends upon the star's n Helium, which is denser than hydrogen, will be reta first, thus giving rise to the helium, or *Orion*, stars. As gas diffuses inward, its place will be taken by hydro which will thus become predominant in the spectrum. its turn, the hydrogen will diffuse into the star, and increasing convection currents will cause a more and r complete stirring-up of the low-lying metallic vapors, w will therefore play an increasingly prominent part in spectrum. Thus the solar stage will ultimately be reac

An interesting point in this explanation is the consi able possibility of variation which stars of different mass in different environments may exhibit. If but little hydr happens to be in the neighborhood, the process of con sation may not result in the attraction of a suffic quantity of this gas to produce the hydrogen type of s trum. Again, the star may be of such low density that unable to attract hydrogen, and thus it may pass into solar stage without exhibiting strong hydrogen lines. T may also be stars of such small mass that, in spite of ha condensed sufficiently to attract hydrogen, they are not to absorb it all, and therefore they may continue to exl a spectrum of the first type without ever passing into

solar stage. Furtherm
age but different mass
condition of *Arcturus*
still in the solar stage,
of hydrogen.

This theory gives a
mentioned spectral phe
cates that the larger s
hydrogen more rapidly
stage, while the smalle
the first type. Schuste
mass would lose heat r
believes that the type
controlled by the ra
absorbed.

It is evident that th
should stimulate much
of different types thro
interest, and doubtless
question of stellar ev
example, tend to clust
others show no such te
graphing the spectra o
northern and southern
for the study of this su
be extended to fainter
reflector, through the
and so designed as to r
all stars lying within
can hardly exceed 20′
feasible to photograph

However, a most in
been instituted by Ka

[1] The objective prism photo

data bearing upon the problem of the geometrical stuc
of the universe and the distribution of stars withi
Through the impracticability of securing all necessary
for stars distributed over the entire heavens, Kapteyn
selected certain limited areas of the sky, so distributed
render it probable that conclusions based upon a comp
study of the stars within these areas will be likely to a
to the heavens at large. The application of the 60-
reflector to the photography of stellar spectra by the ab
mentioned process will therefore be confined, for the
part, to Kapteyn's areas, where many other observers
already gathering information, in accordance with a
which allots to each institution the work for which its ins
ments are best adapted. For Kapteyn's purposes, only
general type of spectrum is required, since he is prim
concerned with questions of distribution and structure, ra
than those which relate to the evolution of stars. The dat
desires include determinations of the brightness, dista
and motions of the stars within the selected areas. The
inch reflector, on account of its great light-gathering po
can assist materially in those portions of this work w
relate to the faintest stars. The investigation of the mot
of these stars in the line of sight is necessary from the
lutional standpoint, because community of motion may u
organic relationship of stars in a group, as in the cas
the *Pleiades*. Photometric investigations and the stud
parallaxes are also required, since, when the distance
brightness of a star are known, its mass can be determi
if certain reasonable assumptions as to the surface brilli
are made. We have just seen how important a factor
mass of a star may be in determining the course of
evolution.

Enough has been said to indicate the nature of the w
which large telescopes may perform. The direct photogra

of nebulae may provide
of years, changes in th
manner and rate of the
study of their spectra n
show the bright line spe
spiral nebulae appear t
With the high dispersion
shown in the constant-
the spectra of a few o
which include most of
analyzed. In this way,
graphs, the spectra of r
can be examined to mu
with reference to their
and to one another. It
with others on the spe
distribution of the differ
selected areas, and stu
of the same stars, migh
several telescopes of the

CHAPTER XXI

THE METEORITIC AND PLANETESIMAL HYPOTHES

In even the briefest outline of the methods of stud stellar evolution, reference must be made to two hypot which are intended by their authors to take the place o nebular hypothesis of Laplace. In both of these, sw of meteorites, rather than matter in the gaseous state supposed to afford the raw material of which stellar sys are compounded. The nature of the swarms, howev unlike in the two cases. According to Lockyer, the mete are to be regarded as analogous to the wandering r cules of gases, in that they move indiscriminately in all d tions and at widely different velocities. Sir George Da has, indeed, demonstrated mathematically that a mete swarm, constituted in this way, is closely analogous gas. The meteorites move rapidly about, colliding witl another from time to time, just as the molecules of a ga supposed to do, according to the kinetic theory. Chamb and Moulton, on the contrary, assume their meteorites revolving in well-defined orbits, and therefore suffering such collisions as may result from certain meteorites taking others of lower velocity.[1]

The most characteristic nebular line is a brilliant o the green part of the spectrum, attributed to an unk gas, which has been called "nebulum." Accordin Lockyer, this line is the remnant of a complicated fl in the spectrum of magnesium oxide, with the brig part of which he found it exactly to coincide. In his

[1] In his explanation of globular and spiral nebulae, and of certain other c phenomena, Lockyer also assumes the meteorites to revolve in well-defined o

the rest of the fluting i
ness of the nebular li
proved, however, by K
of the chief nebular l
observations show, not
not correspond in posit
fluting, but also that it
It is therefore not poss
constituent of the neb
greater probability be
gas, not yet discovered

Lockyer's conclusion
line play an important
He believes that the fr
in the swarms produce
constituents of the met
so that their lines shou
Lockyer tried the exper
orites in a tube, from
exhausted. He found
and the vapor of magn
meteorites. When an e
the gases in the tube at
found to consist of the
flutings given by compo
of magnesium oxide, to
comets, which are kno
meteorites, the flutings
the most characteristic f
certain astronomers hav
in the spectrum of the
confirmed by the majo
see nor photograph an
remaining connection

derived by Lockyer from meteorites therefore depends
the presence of hydrogen in both cases. But hydrog
so universally distributed among the celestial bodies th
absence from nebulae would almost be regarded as an a
aly requiring explanation. It therefore cannot be said
much weight is to be accorded to the experimental ba
the meteoritic hypothesis.

It ought to be said, in favor of the hypothesis, th
provides a simple way of accounting for the existen
the nebulae of substances not represented in their spe
but which appear in stars evolved from nebulae.
nebula is to be regarded as a glowing gas, in whic
substances contained in stars exist in a state of v
it remains to be shown why a very few gases mar
their presence by the appearance of their bright lin
the spectrum, whereas all the other elements produc
lines, and therefore give no indication of their exist
In this connection it must not be forgotten that in
tures of various vapors the spectra of some of the va
appear when an electric discharge is passed through
mixture, while the lines due to certain other vapors re
invisible. Too little has been done, however, in this
portant field of research, to permit final conclusions t
drawn. For this reason no one is at present able to sa
what form the iron, nickel, and other metals, which
sequently make their appearance in the stars, can exi
the nebulae.

This question is, indeed, but one of the many myst
which at present surround the nebulae (Plates LXXX
XC). We have no knowledge, for example, why they
with a steady and unchanging light, since there is no d
evidence that this light is produced either by heat o
electrical excitation. It must not be forgotten that very
nebulae are certainly known to be gaseous: thousand

them seem to give a con
lines of gases do not
presence of solid or li
other causes, is not yet
are condensed out of n
It cannot depend wholl
spiral form, since, as
nebula, which is not a s
of direct relationship b
rather commonly beli
small particles in the
temperature of the enti
since it has been point
ance presented by the
separated luminous pa
may therefore be said t
on the nebulae, not onl
investigating their spe
laboratory experiments

Starting from the
that the chemical elem
stars, are dissociated i
developed a plan of stel
fication of stellar spect
poses that the meteorit
gradually condense int
still uncertain. Accor
and bright-line stars, i
to be higher than that
above the latter in poi
red stars of Secchi's thir
spectroscopists that th
between their spectra a
them would be altog

sation, still involving a rise of temperature, would pro
stars analogous to the Sun, but differing in the impo
particular that, while their temperature is increasing,
of the Sun is supposed to be decreasing. Finally, at
point of maximum temperature, Lockyer places sta
Secchi's first type. Here the meteorites, long since
pletely transformed into the gaseous state, have reached
condition implied by Lane's law, at which the rise in su
ficial temperature, due to continued condensation, is
balanced by the loss resulting from radiation. The decli
period, then setting in, results in the development of
like the Sun, which can be only arbitrarily distinguished
stars of equal, but rising, temperature, lying on the opp
branch of the temperature curve. After the solar stars
the red stars of Secchi's fourth type, and after these,
extinction of light.

This system of classification, considered apart from
hypotheses with which it is connected, has the advanta
providing for both the ascending and descending bran
of the temperature curve. Unfortunately, we are perhap
yet in a position to distinguish clearly between stars of
same surface temperature, in one of which the gain of
is more rapid than the loss, while in the other the re
is true. As already remarked, the assumption that the
stars of Secchi's third type lie not far above the nebulae is
a difficult one to admit. But the classification neverth
deserves careful consideration, and the most searching
that can be applied.

As the late Miss Clerke has well said, the complex s
ture of meteorites suggests a highly developed, rather tha
elementary, condition of existence. This, however, is ha
to be taken as an objection to Lockyer's hypothesis,
the manner in which the meteoritic swarms came into e
ence is not postulated. The planetesimal hypothesis, how

begins with a fully org
motion through space,
hood of another sun, e
effect of the attraction
reduce the immense re
line of mutual attracti
sun, and in the opposite
the Sun is observed to
approaching 300 miles
382 miles per second,
would escape the powe
space, never to return.
near the Sun, the tende
augmented along the li
protuberances would d
from opposite ends o
with this line.

According to the p
tuberances would be fo
past one another arou
The effect of mutual a
great arms to assume
materials revolve abou
Moulton has shown, by
such a result might a
the spiral nebulae m
LXXXVIII–XC). Al
Sun would necessarily
that it would rapidly c
dition.[1] The outer p
naturally be formed fr
while the inner extrem

[1] How, it may be asked, can
many years? And why do we n
spectrum?

depths, where the heavier elements are found. This possibly explain the lightness of the outer planets of our system, and the great relative weight of the inner ones. changing attraction of the neighboring star might also a series of irregular outbursts, accounting for the knotty uneven distribution of the matter in the spirals (Plate Chamberlin points out that a very small fraction of the mass, not exceeding 1 or 2 per cent., would be amply suffi to supply all of the matter required to form a plan system like our own.

In the further evolution of the system, the central is supposed to form the sun, the knots to serve as the r about which the planetary materials gather, and the re ing diffuse nebulous matter to be swept up by the nuc absorbed by the sun. The building-up of the planets i supposed to take place, as in the nebular hypothesis, si through the gravitational attraction of the planetary r on the matter surrounding them. On the contrary, the agency is assumed to be a gradual accretion of the through collisions of isolated planetesimals (meteo resulting from the intersection of the individual o brought about periodically through the rotation of thei of apsides. Thus it is held, according to this hypot that the Earth was never a molten mass, but that it was up by gradual accretions. Chamberlin was led to this of the condition of the Earth's interior from various logical considerations, which seem to him inconsistent the hypothesis of a fluid origin.

If this book were a treatise on stellar evolution, these questions would require much fuller discussio criticism, and space would necessarily be devoted t remarkable phenomena of variable and temporary star tidal investigations of Darwin and their possible bearin the evolution of double-star systems, and many other sub

which have not receiv
said, however, to give
which an observer con
upon to attack, and t
observational methods

CHAPTER XXII

DOES THE SOLAR HEAT VARY?

One does not often stop to think of the delicate ba
that determines the conditions of life on the Earth. I
is obvious enough that a small change in the intensity
solar radiation would suffice to transform the climate
temperate zones to that of the equatorial or polar re
A greater change might soon result in the complete de
tion of life.

It is therefore a matter of the most vital intere
inquire into the source and constancy of the Sun's
What fuel maintains the great fire that warms and ligh
and supplies, through its beneficent influence on gr
crops, the food that we consume? Is the average
influx of solar rays constant and unchangeable, and a
justified in our tacit belief in the inexhaustibility o
supply? Such thoughts, seriously pondered by stude
solar physics, have led to extensive investigations,
must go on for many years before these questions c
finally answered.

As we have already seen, the contraction of a neb
mass to form a star, or a sun like our own, must res
the liberation of much heat. Indeed, the total solar
tion in the course of a year can be accounted for on the
position that the Sun's diameter decreases about 250 f
this time. Since the discovery of radium, which pos
the remarkable property of sending out heat, with littl
dence of exhaustion, for very long periods of time,
been suggested that this substance, if it exists in the
may be the source of part of its radiation. Radium ha

yet been detected in th
may lie at low levels, w
the absorption that pro
The abundance of heliu
which gives off this ga
may perhaps exist with

If radium really su
Sun's heat, its ultimate
decrease in the solar ra
however, that there is a
of such a contingency
profitable speculation.

We may take it for
radiate heat, at practica
centuries to come. Bu
lutely constant? May
magnitude to affect c
reflected in the ebb and

Until a short time a
only the roughest way.
through a regular cycle
years. A curve was ac
number of sun-spots, a
ing, for example, the v
were thought to show a
held that the price of
activity, as measured b

But the correspond
perfect, and might hav
fall and temperature cu
more satisfactory, but t
tive stages, and little th
has been learned. The
Commission of the Int

may be expected to help matters, but much will depend
the appliances used to measure the solar radiation, ar
determine the amount of heat lost by absorption in
Earth's atmosphere.

The most elaborate study of this question yet ma
due to the late Secretary Langley, of the Smithsonian I
tution. He long ago recognized that the chief difficul
the problem lies in the constantly varying absorption o
air above us. If measures of the solar radiation coul
made from a point outside of our atmosphere, any obs
fluctuations would be due to the Sun itself. But nea
level of the sea the difficulties are very great.

To diminish them, Langley led an expedition to M
Whitney in California. Here, at an elevation of over 1
feet, the denser and more variable half of the atmosph
left below. The precision of the measures was thus gr
increased, but the expedition was not able to remain
enough to determine whether the so-called "solar const
of radiation is actually a constant, or undergoes chang
an irregular or a periodic character.

Langley strongly felt the importance of continuing
work with the greatly improved apparatus develope
Abbot and others at the Smithsonian Astrophysical O
vatory in Washington. He therefore recommended the
Carnegie Institution make provision for further resea
of this nature at a mountain station. When the Solar
servatory was established, a co-operative arrangement
the Smithsonian Institution was accordingly entered
and measures of the solar constant were made daily by A
on Mount Wilson during the summers of 1905 and 190

The apparatus used in this work is most ingenious.
independent operations are carried on simultaneously:
direct measurement of the solar radiation with some for
pyrheliometer; and the determination of the atmosp

absorption, for all the c
(Plate XCI).

The pyrheliometer,
the rise in temperature
of liquid exposed to th
phere, pyrheliometer n
the desired informatio
is far greater than sho
through a much shorte
vations must be repeat
morning.

The bolometer, in
to radiation that it w
less than one-millionth
very fine threads of
mounted side by side w
One of these is shielde
to be measured. The
of a "Wheatstone's bri
age battery, so that a fe
them. A galvanometer
anced in the circuit tha
flowing through the t
moment the resistance
radiation falling upon
an amount which measu

In practice, the sol
across the exposed b
needle then swings ba
when a dark line or
bolometer, and large
the spectrum is being
the needle a minute mi
a spot of light upon a p

ism that moves the spectrum across the bolometer ca this plate to travel slowly downward. Thus the deflect of the needle are photographically registered upon the p With the aid of such curves the total atmospheric absorp measured separately for each region of the spectrun accurately determined. The reduced pyrheliometer readi corrected in this way for absorption, give the value of solar constant.

With such highly developed instruments the systen study of the solar radiation was pursued in Washington. the best days, which came none too often, the refinemer the method permitted the atmospheric absorption to be el nated, even at this station so near the level of the sea. was soon found that the values of the "solar constant" not constant, but variable. Indeed, differences as grea 10 per cent. of the whole were encountered. Was it sa conclude that the solar radiation undergoes variations of considerable amount?

On Mount Wilson the escape from the denser air of valley, the purity of the upper sky, and the constant suc sion of perfectly clear days, permitted the question t put to the test. Day after day the Sun was followed thro the heavens, from a time soon after it rose above the eas mountains to its culmination near the zenith. Someti the work was continued through the afternoon, but the m ing observations proved to be sufficient.

As soon as the curves had been measured and redu and the pyrheliometer observations plotted, the full ad tages of the mountain station appeared. Not only was precision of the work much greater than before: even r important was the fact that daily observations, continued many weeks, brought the exact nature of the phenomenc light. Through the latter part of the month of July, 1 the value of the solar constant increased slightly from

to day, until it reached
same gradual manner.
that the solar heat had
not to be ascribed to an

Does this mean a g
tion, caused by an actu
of the Sun? Or had tl
decreased for a time,
Much study will be req
the uncertainties may b
observations have beer
represented by numero
ably be taken to indi
ous and more violent
quantities of heat fro
At times of great solar
increased radiation.
the diffusion through
thrown upward by the
such periods of activity
persisting after the su
result in a reduction of

Evidently a compari
tions of various kinds,
heliograph plates, beari
the flocculi, afford an
absorption of the solar
allowing the solar ima
and photographing the
ing plate. During the
of work were carried c
with Abbot's measurem
the results are discusse
on the subject.

But the work is barely started, and must be continue many years under the best conditions. Simultaneous ob vations at several widely separated mountain stations greatly to be desired, to make certain that local change our own atmosphere are in no wise concerned in the appa solar changes. Moreover, the work should go on wit the interruptions caused by the rainy season. If, for exan a bolographic outfit were established at the Solar Observa at Kodaikanal, in south India, at an elevation of 7,000 the dry season there would correspond with the rainy se in southern California. An Australian station might accomplish very important results. It is to be hoped adequate provision may soon be made to carry out this portant work.

But, it may be asked, must not such fluctuations of solar radiation, if real, be the cause of marked change terrestrial temperature, easily detected and obvious in t effects? Abbot believes that the thermometric record actually reflect these solar variations, but Newcomb holds contrary view. It is evident that complex meteorolog phenomena may be involved, and that their disentangler may require long-continued research. For this reason studies of the solar radiation undertaken by the Inte tional Union for Co-operation in Solar Research, the operation in meteorological work set on foot by the S Commission, and the labors of such an institution as observatory recently established on Mount Weather, ginia, by the United States Weather Bureau, should p of value. In the exhaustive study of so important a prol the cordial co-operation of many investigators is essenti success.

CH

THE CONSTRUCTI

THE grinding and p
a variety of operation
memoir *On the Mod*
Making and Testing of
tative treatise on the
operations, taken in lar
be of interest here.

It is first necessary
The disk (of plate glas
Works, of St. Gobain, I
the Solar Observatory
thick, and weighs a ton
requirements for a large
for a lens through whic
is merely a support for
face, from which the li
glass. For this reason
not necessary. Nevert
striae and other eviden
should contain no large
they do not lie on the
most important conditi
caused by imperfect a
detected by a test with
ever, cannot be final, as
telescope objective illus

[1] Published by the Smithson

annealed and was supposed to be suitable for its pur
During the process of grinding it flew to pieces, on acc
of internal strain, the serious nature of which had not
recognized in the test with polarized light.

It may not be obvious why the disk must be so t
when its sole purpose is to support the thin film of s
on its accurately figured face. Great thickness, how
is absolutely essential, to diminish the effects of ben
due to the weight of the glass and to temperature cha
The thickness of a mirror should not be less than
eighth or one-seventh of the diameter. Even with
thickness a special support system is necessary to pre
flexure.

Glass is chosen in preference to other materials for
scope mirrors because of its uniformity of structure,
parative ease of working, and capacity for a high pc
Its lightness, when compared with such substances as sp
lum metal (formerly employed for telescope mirrors
an important advantage. Furthermore, a surface of
silver, first used by Foucault, reflects a much larger pro
tion of light than polished speculum metal.

The grinding-machine, designed and constructed
Ritchey for his work on the 60-inch mirror, is show
Plate XCII. The glass disk rests on a heavy cast-iron t
table, carried by a vertical steel shaft. Between the l
surface of the glass (ground flat) and the turn-table are
thicknesses of Brussels carpet, which form an admi
support during the grinding and polishing process.
edge of the glass is ground true by means of a rap
rotating iron face-plate, held against the disk while the t
table is slowly rotated. The cutting material is powd
carborundum, carried down between the glass and the
plate by a slow stream of water. After the edge-grin
is completed, the two faces of the glass are ground p

and parallel, before the p
faces concave is undertak

The grinding-tools e
plates of cast-iron, stron
into a series of small sc
two sets of parallel groc
another. The tool rests
in Plate XCIII it is sh
employed to swing the
During the grinding the
also kept in rotation, is
of strokes from four to
of the arm shown above
right-hand extremity th
which moves back and
supported on an adjusta
of the grinding-tool on
so as to bring the strok
near the edge. If it is
is being cut away too r
edge and the grinding
corrected. The tool is
great length of time, to
glass.

For the grinding proc
are prepared in the foll
rundum is mixed with w
settling for two minutes
of the bucket and the lic
borundum and the finer
bucket. After the conte
allowed to stand four mi
the "two-minute" carbor
set aside for fine grinding

rundum which has remained in suspension for periods
one hundred and twenty minutes, or even longer, is prep
These very fine grinding materials are used to give
smooth and almost polished surface obtained after the g
ing with coarser carborundum is completed.

A perfectly true Brown & Sharpe steel straight-ed
used to determine whether the surface of the glass is ap
imately plane. When it is found to be sufficiently s
the preliminary work, the fine grinding is comme
beginning with two-minute carborundum and contin
with finer grades. In this work the iron grinding-t
counter-poised by placing weights on a lever arm
nected by a shaft with the tool. The pressure is red
from one-third pound to the square inch for the five- or
minute carborundum, to about one-twelfth pound per sc
inch for the one-hundred-and-twenty- and two-hundred
forty-minute carborundum. Unless this precaution is t
there is great danger of scratching the glass.

After being fine ground, the back of the mirr
polished with rouge in the manner described later.
great pains are taken with this surface, although it is
very nearly plane, and is then polished so as to permit si
ing (Plate XCIV). It is desirable to silver the back o
mirror, as well as the front, in order to prevent temper
changes from affecting the two surfaces in unequal de

The front surface, after it has been given a plane fi
is ready to be made concave. For this purpose a cc
iron tool, of suitable curvature, is employed. In the ca
the 60-inch mirror the radius of curvature is 50 feet.
curvature of the tool, and also of the glass, is tested
time to time by a spherometer. This consists of a tr
with a micrometer screw at its center, which permit
deviation of the surface from a plane to be accurately d
mined. After the desired curvature has been secured

fine grinding is carried
smooth and ready for p

The polishing and fi
built up of narrow strip
prevent change of figur
with squares of rosin, of
can be determined only
are finally coated with a
the polishing surface.
small hard particles tha
polishing material are
reducing the danger o
polishing, the tool is pl
and pressed against it,
that it may acquire th
After pressing for som
appear smooth and bri
begin. This is accomp
rotating glass, by the n
case of the grinding
powdered jewelers' rou
plate glass. The fine
and coarser particles b
used for carborundum.
water, is applied to the
wide brush of cheese-clo

The greatest precau
polishing process to av
room in which the work
to eliminate danger fro
the Solar Observatory c
tered walls and ceilings
screen is hung above th
particles. The cement fl

polishing is in progress. The windows are double and fully sealed, outer air being admitted to the room throu cheese-cloth filter. The temperature is maintained cons within two or three degrees, by means of a hot-water fur controlled by a thermostat. The motor, driving-shaft apparatus for varying the speed of the grinding-mac are carefully inclosed, only the slow-moving belt comin into the room. No one is permitted to enter the room e the optician, who wears a surgeon's gown and cap. observing such precautions the work may be continue months without producing even microscopic scratches i glass surface.

We may now assume that the glass has been poli after receiving an approximately spherical surface. It becomes necessary to apply a more accurate test tha spherometer permits. For this purpose the glass is tu into a nearly vertical position, where it is supported by a edge-band (Plate XCV). An artificial star, consistir a hole about $\frac{1}{300}$ of an inch in diameter illuminated l acetylene lamp or other brilliant source of light, is plac the center of curvature, 50 feet from the glass surface. light from the artificial star then falls upon the disk a reflected back so as to form an image close beside the hole. If the surface is perfectly spherical, it will ap when examined by the eye placed at this point, to be liantly and uniformly illuminated. With an eye-piece image of the pin-hole will then be perfectly sharp, sho the most minute details or irregularities of the hole itse

It is much more probable, however, that the surface have many zonal errors. To detect and interpret these "knife-edge test," due to Foucault, is employed. If al zones come to a focus at the same point, and a knife ed moved across this point, while looking at the glass, the will be cut off instantly from all parts of the disk. If,

ever, the curvature of
the average curvature, t
or receding rings on an
The effect is as though
producing an appearan
The test is so sensitive
inch can be detected.
for a few moments on t
will cause a swelling eas
test.

The process of figu
and low zones by mea
and position of which
the results of the knife-
cal form has been obtai
of changing the spheric
As is well known, the p
spherical surface, will n
point, but in an irregu
paraboloid, however, b
focus, and produces a p
the 60-inch mirror, whi
paraboloid is deeper th
disk by a quantity less
figuring are required, h
ence, because of the ne
paraboloid precisely th
surface from the center
each narrow zone of t
covered by a cardboard
calculated radius. The
this may be appreciate
deviation of any zone f
boloid must not be grea

would correspond to a change of $\frac{1}{100}$ of an inch in radius of curvature.

When parallel light is available, the difficulties of se ing a perfectly satisfactory test of a paraboloidal mirro greatly reduced. In this case the mirror, when seen its focal plane (25 feet from the glass, or one-half radius of curvature) appears like a uniformly illumin plane surface when a perfectly paraboloidal form has obtained. This method of testing with parallel light been developed by Ritchey, and was used by him to se the last degree of perfection in the figure of the 60- mirror.

As already explained, the problem of mounting a l mirror is quite as serious as that of figuring it. It is ne sary, in the first place, to support the mirror in such a that it will retain its form, without bending, in any pos of the telescope. Furthermore, it must be held so th will not slip laterally, since the slightest change in the tion of the mirror with respect to the tube will cause a placement of the star images on the photographic p The mirror, thus supported, must be carried at the l end of a tube, of skeleton construction, open at the top, so mounted that it can be pointed toward any part of heavens and made to follow the apparent motion of stars by rotation about an axis parallel to the axis of Earth. Strength and stability of the mounting, free from flexure, perfection of optical and mechanical const tion and adjustment, and the greatest precision of drivin all these conditions must be met before a large reflector be expected to give satisfactory results, in the more exac departments of photographic work.

The difficulties thus presented have been most success solved by Ritchey, whose design for the mounting of 60-inch mirror is shown in Plate XCVI. The telescope

is hung between the arn
is bolted to the upper
hollow forging of nickel
sponding to the latitud
thus rendered parallel
screws, by which the ba
its pier, permit this adj
cision. In order to reli
the upper and lower be
float, 10 feet in diamet
below the fork. This fl
cury. Thus the entire i
and in this way the fric
minimum.

The 60-inch mirror r
a support system consist
levers, which press agai
tribute the load. A sim
the circumference of th
The path of the rays f
Plate XCVII, Figs. 1, 2
(the Newtonian telesco
the mirror, are reflected
point just beyond the en
however, by a plane m
them at right angles a
graphic plate, which is r
the upper end. In this
ment is 25 feet, and the
magnification.

If, however, it is des
work, the advantages of
arrangement is adopte
bearing the plane mirro

substituted for it. This carries a hyperboloidal m which returns the rays toward the center of the large n and causes them to converge less rapidly. They then a small plane mirror, supported at the middle of the near its lower end, which sends them to one of the follc instruments, mounted in the focal plane: (1) a double plate-holder, carrying a sensitive plate, for the photogr of the Moon, planets, bright nebulae, etc., with an equiv focal length of 100 feet (Fig. 3); (2) a spectrograph mo in place of this photographic plate, in which case a c mirror of different curvature is employed, and the equiv focal length is 80 feet (Fig. 4); or finally (3) a third c mirror may be used and the plane mirror inclined so form the star image (after sending the light down thr the hollow polar axis) on the slit of a powerful spectrog of 13 feet focal length, mounted on a pier in a cons temperature chamber (Fig. 2). In this case the equiv focal length is 150 feet.

The telescope is moved in right ascension or declin by electric motors, controlled from the floor of the obser room. The driving-clock moves the telescope in right a sion by means of a worm-gear, 10 feet in diameter, ca by the polar axis. The cutting of the teeth of this w gear is a mechanical operation requiring the highest prec of workmanship. Each tooth was spaced off by mean finely divided circle attached to the polar axis, and read a microscope. The rotating cutter was driven by an el motor. After all the teeth had been cut, the worm and w gear were ground together for many hours, until all s residual errors had been eliminated. The operation completed with jewelers' rouge, which leaves a smooth highly polished surface.

All of the heavy parts of this mounting were made, Ritchey's designs, by the Union Iron Works Compar

San Francisco. They w
the mounting has been e
(Plate XCVIII). Her
the smaller parts, includ
slow motions, motors,
All of these parts were
shop, which is equipped
for work of this kind (

As soon as this moun
mirror will be put in
tested, by actual photog
be necessary to transpo
an operation of conside
ings are very large, and

The building for th
struction throughout (
be shielded from the Su
mitted to circulate in th
60 feet in diameter, w
either rapidly, when p
to another, or at a slo
to keep the opening (1
end of the telescope tu
observer, when photog
stand on a platform sus
with it. The double-s
and nebulae will be p
with the Yerkes telesco

CHAPTER XXIV

SOME POSSIBILITIES OF NEW INSTRUMENTS

In looking toward the future and endeavoring to ima what appliances will be employed by the astronomer o next generation, the line of least resistance is to conside possibilities of improving existing telescopes and the a iary apparatus employed with them; for the previsic more radical departures is beyond our province. It is to predict that the equatorial refractor, of which the and Yerkes telescopes are types, will hold an impo place in observatories for many years to come. The with which such instruments can be pointed toward any of the heavens; the absence of reflecting surfaces; the manence of object-glasses, as contrasted with the nece of silvering mirrors from time to time; the convenient tion of the observer at the lower end of the tube, rather at the upper end of a Newtonian reflector: these and considerations point to the long-continued use of the stan refractor. In its most perfect form this instrument is capable of some improvements, the most important of w will be the introduction of truly achromatic object-gl capable of uniting the rays of all colors at the same f

It seems probable that the uses of the equatorial refr will be confined more and more to visual observations to certain departments of photography, especially involving great precision of measurement or the incl of large fields on a single plate. For the latter worl refracting telescope, particularly in the portrait-lens possesses great advantages, on account of the very lir field of the reflector. It does not at present appear

able to increase the ap
of 40 inches reached in
power of such an ape
tions are good enoug
ciently great for the m
Increased light-gatheri
for the investigation of
effectively obtained thr
scopes. Increased foc
needed to give larger
through the use of son
now consider what ty
most serviceable in ph
of the Sun, stars, and r

Many important inv
scope giving a sharply
at a fixed position with
such a telescope must
ment is exposed to the
and the laboratory cond
of the largest and mo
troheliographs. The
requirements in a very
culty with this instrum
the change of focus wh
time to the Sun. Whe
XV are taken, these ob
rent work with the 5-fo
spectrograph. But wit
with a spectroheliograp
of focus during the exp
is probable that by sub
now used in the Snow
upon their rear surface

front surfaces, the tendency to distortion could be overc
For a very thick mirror would resist the bending w
results from the expansion of the front surface; and ev
the figure were changed, the compensating effect prod
by heating the rear surface should restore it. But the S
telescope is fully occupied with its present work, for w
it is well adapted. Accordingly, a new type of fixed
scope has been devised for the purpose of supplementin
Snow telescope, particularly in photographic work invol
long exposures.

In the new instrument the coelostat, provided with
rors a foot thick, will be mounted at the summit of a
tower 65 feet in height (Fig. 7). From the second m
the sunlight will be sent vertically downward to a 12-
object-glass, mounted a short distance below it. This ob
glass, of 60 feet focal length, will form an image of the
near the ground level. The new instrument will thus co
essentially of a fixed refracting telescope, pointing dir
to the zenith and receiving light from a coelostat and se
mirror.

The spectroscopic laboratory at the base of the tower
be excavated in the earth, to insure constancy of temper
and great stability of the instruments it will contain.
these, the one shown on the left in Fig. 7[1] is a Lit
spectrograph, similar to the one employed with the S
telescope, but of much greater power. This instrument
have a focal length of 30 feet, and be provided with a l
plane grating. On the right is shown a spectroheliogra
30 feet focal length, designed for extending the monochro
photography of the Sun to many of the finer lines of
spectrum (p. 236). The atmospheric calm that prevai

[1] This is only a general diagram, omitting all details, such as the steel ho
the base of the tower, which covers the upper ends of the spectroscope and s
heliograph; the small electric elevator, to convey the observer from the bot
the underground laboratory to the summit of the tower, etc.

Mount Wilson during t
the inner tower to be
stayed in position by st
ment, it is found that t
of the structure, an oute
will be erected to shiel

It remains to be see
meet the rigorous cond
instrument for solar re
should be less affected
than a horizontal beam
coelostat and object-gl
advantageous. Should
ment of larger aperture
may ultimately be cons
of providing a very larg
of spectroscopic and sp
able enough that some
better than this, but th
present time give reaso
will prove satisfactory.

Since the principal
struction of a fixed tele
of the mirrors by the S
geneous disks of fused
for mirrors, in place of
of fused quartz is only
hence it is but slightly
Many small quartz disk
nace at the Solar Obser
bubbles, which cannot b
by stirring, have prove

[1] Or perhaps with fine wire
heat sufficiently in sunlight to p

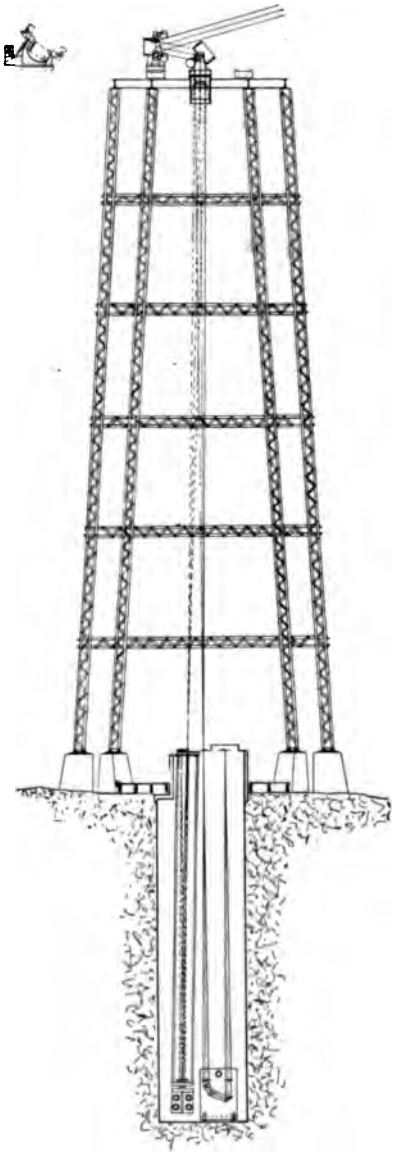


FIG. 7
Vertical Coelostat Telescope

of these disks for optica
success in the geophysic
tution, where an electri
quartz to be fused und
ciently promising to lead
of suitable design, were
in diameter might be ma
a furnace, it has seeme
in this direction until
thoroughly tested.[1]

Another important ne
of ruling gratings of mu
Rowland. The best Row
possible the great adva
spectroscopy, have a r
The resolving power of
number of lines it co
why it is not desirable th
per inch. If a good 15-
with lines from 10 to 1
in solar spectroscopy w
grating, if one of the s
exactly what is require
of photographing the
If used in a spectrogr
length, it would furnis
spectrum much superior
service in the photograp
the solar rotation, and n
purpose the spectra of o
to fourth) should be b

[1] Since the above was written
tested. The thick mirrors are s
remain constant during the long
graph (Plates CI and CII).

should, of course, be so high as to permit the theore resolving power to be attained. In view of Michels recent work in ruling 8-inch and 10-inch gratings, realization of his plan for the construction of a mac capable of making gratings of much larger size is r earnestly to be desired than that of any other project the development of spectroscopy.

Still another important need of the spectroscopi homogeneous glass, in large masses, for prisms. At present time it is almost impossible to obtain prism large size that will give good definition. The repe failures of the best makers of optical glass indicate that problem is not an easy one, though it can probably solved. A careful study of this question, made with sp reference to the possibility of improving the present met of annealing, should yield valuable results. Large pr are urgently required for use in stellar spectrographs of l aperture and high dispersion, such as the one which is t mounted in a constant-temperature chamber in conjunc with the 60-inch reflector. However, if sufficiently l and perfect gratings can be obtained, which concent nearly all of the light in a single spectrum, they ma better for this purpose than prisms.

In the further development of solar research, no ins ment seems to offer more possibilities than the spectroh graph. Recent experiments with a temporary spectroh graph of 30 feet focal length, used in conjunction with Snow telescope, have demonstrated the feasibility of ph graphing sun-spots with the lines that are strengthene weakened in their spectra. The resulting pictures show distribution of the corresponding vapors in and around spots, and should be capable of throwing much new l on solar phenomena when taken daily and systemati studied. It is expected that the 30-foot spectroheliog

of the "tower telescope
even the great dispersi
quate for work with th
the photograph is to r
or vapor corresponding
be as wide as the secon
adjoining continuous sp
the image produced by
solar spectrum contain
any one of these may b
comparable in interest w
hydrogen and calcium
effort should be spared
perfection of the spect
tions of this instrumen
flocculi; the absorption
of the flocculi and pro
in accelerated progress
taken in rapid successi
kinematograph; the us
heliographic work: the
leave no doubt that this
opened, and still contai

Passing over other
one's optimistic belief i
now inquire as to the
promising for photogra
stars and nebulae. In
as in the case of the Su
laboratory. For this re
ing telescope seems to
Even when a fixed imag
trated in Fig. 2, Plate
lying within a certain

temperature laboratory, for analysis by the most pow spectrographs. As already explained, such a telesco also adapted for many other classes of work, either in principal focus of the great mirror or with an enla image given by a convex mirror, after the manner of C grain.

As an object-glass increases in size, the absorption, to its increased thickness, rapidly diminishes the percen of light it transmits. The loss is especially serious fo blue and violet rays, since these are absorbed more compl than the red and yellow. In the case of a mirror, the l passes through no glass, but falls on a surface of pure si from which it is reflected to the focal plane. Thus e square inch added to the area of a telescope mirror m a proportional increase in the light-gathering power. is evident that if the mechanical and optical difficu can be overcome, reflecting telescopes much more po ful than any now in existence can advantageously be structed.

With this object in view, Mr. John D. Hooker has sented to the Carnegie Institution a sum sufficient to chase for the Solar Observatory a glass disk 100 inch diameter and 13 inches thick, and to meet other expe incident to the construction of a 100-inch mirror for a ref ing telescope of 50 feet focal length. The construction telescope so far surpassing all previous instruments in must, of course, be partly in the nature of an experin The immense block of glass will weigh 4½ tons, four and half times as much as the disk of the 60-inch mirror. difficulty of providing a mounting capable of carrying it the necessary precision is not slight. The glass is certa be more or less distorted by temperature changes, w would ruin its performance if not obviated. The atmosp conditions, even on Mount Wilson, may not be sufficie

good to permit so great a
Of these and other obs
and he does not unde
perceives and appreciat
has himself invented a
that experiment is nece
not hesitate to provide
experiment on a large
outcome.

In the first place, th
homogeneous glass dis
obtained. Our long ex
pany of St. Gobain (I
insuperable difficulty w
able company has cast
Ritchey has made man
smallest sizes up to 6
quality of the disks h
60-inch, 8 inches thick
the smaller ones. We
the St. Gobain Compan
a satisfactory disk, 10
thick, can be produced
the order we have give

As for the work of
has watched the progr
likely to doubt Ritche
task. The method of
will apply as well to a
eliminates the necessit
ing touches, and has y
loidal figure in the cas
fident that he will find
mirror to this highest

The mounting should offer no great obstacles, espec as it will not be built until the mounting of the 60- has been thoroughly tested on Mount Wilson. In t days of large and perfect machinery, the mechanical culties are much less formidable than they would appeared twenty years ago. On this score, therefore see no cause for fear.

The prevention of change of figure due to changing perature should not prove a very serious problem. Du the fine nights of the best observing season on Mount W the temperature remains almost perfectly constant after 9 It will therefore only be necessary to maintain the m (or possibly the entire telescope) at approximately this perature throughout the day, by means of suitable refrig ing machinery. In the long periods of cloudless weathe change of temperature from night to night is extre small, so that little difficulty should be encountered on score. If the slowly falling temperature during the e evening should prove to give trouble, the observational may be deferred until after nine o'clock. The dome building, like those for the 60-inch reflector, will be so structed that no air can enter during the day; they will be shielded from the heat of the Sun. The problem i course, altogether different from that encountered in case of the Snow telescope, where the mirrors are requ to give good images in spite of their exposure to d sunlight.

Assuming that these various difficulties can be suc fully overcome, it still remains a question whether the at pheric conditions on Mount Wilson will be sufficiently to permit the telescope to give satisfactory images. cannot be definitely determined until after the 60-inch refl has been used for some time. Even if it should prove, h ever, that only a very few nights in the course of a yea

be utilized to the fulles
a telescope would never
average summer condit
in the eastern part of th
can undoubtedly be ob
as the photography of s
heat radiation of the s
light which this mirror
larly suitable for spectr

It need hardly be
suitably mounted, will
scheme of research of th
tion of stellar evolution
scopic study of stars b
ments. With the 40-i
was impossible to obt
negative, as to the tran
fourth type. The larg
a 100-inch reflector (w
as bright as the 40-incl
of finding possible inte
bearing upon the relatic
only a single instance, b
sidering our programme
reflector should be equ
tography of the numer
which should be broug
length of 50 feet; minu
in the hope of detectin
with very high dispersi
The remarkable calm of
should assist materially
the tube, caused by t
serious drawback under

It is impossible to predict the dimensions that ref
will ultimately attain. Atmospheric disturbances,
than mechanical or optical difficulties, seem most lik
stand in the way. But perhaps even these, by some p
now unknown, may at last be swept aside. If so, the a
omer will secure results far surpassing his present ex
tions.

CH

OPPORTUNITIES

I SHALL never forget
learned of the spectrosco
and the endless possibil
applications in astronom
asm, and kindled a stro
visual study of flames, w
aroused an ambition to
accomplished, by subst
observing telescope. B
too small, so I built a l
Rowland was making hi
est size was secured, a
marvelous increase in r
mented beauty of the s
the solar prominences,
research. But none of
which I have enjoyed th
powerful instruments, h
work, much of which wa
apparatus of my own co

These remarks are ca
heard of great moder
am told, believe that t
the more powerful equi
tages of other investig
grounded, it might fairl
tories are worth their c
teaches that much of t

amateurs, usually with modest means and in unfavorabl
mates. To discourage this class of workers, unfettei
they are by the traditions of institutions, and driven by
own initiative into unexplored fields, would be a serious
hardly to be atoned for by any services the larger obs
tories can render.

We may therefore inquire whether useful work, of
a nature as to contribute in important degree to the prc
of science, can still be done with simple and inexpe
instruments. This question may at once be answered i
affirmative. The results of amateur observations ma
only be useful—they may equal, or even surpass, the
products of the largest institutions. Great care must be
cised in choosing the subject of research, in constructin
instruments, in making the observations by the best me
and at the most favorable hours, and in the reductioi
discussion of the results. If such precautions are obse
discouragement will soon give way to confidence and su

Take, for example, the direct photography of the Sun
2-inch objective, of 40-feet focal length, will give bea
solar photographs, over 4 inches in diameter, perf
adapted for the study of the solar rotation, the proper mo
of the spots, and other important purposes. Details
rated by less than two seconds of arc will not be resolv
these photographs, but in many classes of work little
would result from increased resolving power. Such a
jective should be mounted so as to send the beam horizor
(better vertically) across shaded ground, or within a buil
to the photographic plate. If no coelostat is available, a
mirror, with optically plane reflecting surface, will serv
needs of direct photography. It is only necessary to mo
on a wooden support, so that it can be held at the angle req
to reflect sunlight through the objective. The exposu
made by the rapid motion of a wooden shutter, pierced

narrow slit with brass
plate—are very short,
during this time can b
simple driving mecha
mirror should be shield
by the American part
Venus across the Sun
objective and larger mi

It will probably be
occurs in the early m
heated. A careful stu
ditions before selecting

Solar photographs,
one to several hours,
with striking results.
a long series of photo
examined with a kineto
rotating under one's ey
more rapidly than thos
proper motion, in caus
the same latitude, sho
Even more interesting
forms of spots, and the
which have never yet b

The same horizonta
would give an admirabl
objective should, if poss
and from 40 to 60 feet
be increased in the san
with its plane parallel
very thick—3 inches o
little by sunlight. A
the beam to the spec
(Plate LVIII). If th

should be remembered that almost all the parts can be m
of hard wood, thoroughly soaked in melted paraffine, to
vent warping. The bearings are practically the only
that need be of metal. A cheap clock movement, with h
spring, will serve for a driving-clock, or a small ele
motor may be used. With moderate ingenuity, any am
accustomed to the use of tools can build such an instru
for a very small sum.

The spectrograph is even more simple. It should
the Littrow form (p. 153), and the aperture of the s
plano-convex lens that serves for both collimator and ca
should be from 1 to 1½ inches. Its focal length wi
determined by the diameter and focal length of the obje
used to form the solar image on the slit. If these
inches and 60 feet, respectively, the ratio will be 1:
Hence the focal length of the spectrograph lens should be
times its aperture, or from 15 feet to 22 feet 6 inches.
grating should be a 2-inch Rowland, or, if this is too ex
sive, a good replica by Ives, Wallace, or Thorpe. The r
cas have the disadvantage of being made on transparent f
for use with transmitted light; but they can perhaps be
verted into reflecting gratings by silvering.

The collimator-camera lens should be mounted on a
tical wooden bracket, arranged to slide 3 or 4 inches
focusing. The grating may also have a wooden sup
consisting of a bracket, which can be tipped forwar
back, mounted on a circular wooden table, permitting
tion about a vertical axis in the plane of the grating.
rotation is necessary in order to bring different spectra
the photographic plate, or to pass from one region to anc
in the same spectrum. The height of the spectrum or
plate can be adjusted by tipping the grating forward or
It is also necessary to make the lines of the grating par
to the slit; this can easily be done by hanging the bra

from above, and defi
passing through woode
Plate CIII shows a w
ular use as part of a
length in the laborato

The extreme simpl
ment is illustrated by
movable by a screw, i
a hole bored through
holder, held in a fram
many narrow spectra
In another similar ins
port stands on a pier,
all light from the roo
slit.[1] In this case no
lens. The latter is m
distance from the slit

In spite of the simp
graph, no better instr
back—the reflections
—is easily removed by
in Plate CIV). Woo
at the Solar Observat
satisfactory.

Any of the solar sp
can be done with such
even with only an inch
ration of very close sol
solar rotation, the rem
of the center and limb
ena can be studied by
success. The exposur

[1] This room is part of a l
shop of the Solar Observatory.
used for the transmission of li

a spectrograph of larger aperture, but this is not a se obstacle. Indeed, it may be said that at the present only two or three observatories in the world are using e ment as powerful as this for the classes of solar work enumerated.

I might go on to describe a wooden spectroheliog fitted up with spare lenses and prisms, which gave exce results with the Snow telescope before the 5-foot spe heliograph was completed. Indeed, the photographs quite equal to those taken with the latter instrument, e that they did not include the entire solar image, whi unnecessary for many kinds of work. The small coel telescope described above would give as good results a Snow telescope with such a spectroheliograph, except tha exposures would be longer. The entire apparatus is e within the reach of any intelligent amateur of limited m

Those who desire to undertake solar work would do to procure the *Transactions of the International Unio Co-operation in Solar Research*.[1] The aim of the Uni to encourage co-operation among observers, in the va fields where this is desirable. For example, it is impos in visual observations of sun-spot spectra, for one perso make a thorough study of more than a limited region. mutual agreement, the spectrum is therefore divide among many observers, who record their results on a com plan. Spectroheliographs, distributed from India a Europe to California, are also operated in harmony, an operation is practiced in other fields as well. Apart such routine, however, every observer is encouraged t on his own initiative, for the Solar Union recognizes the greatest advances will come from individual effort, w no amount of co-operation can replace.

[1] Vol. I was published by the University Press, of Manchester, England, i Vol. II will soon appear.

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phere, 129; solar radiation,
liometer, 215.
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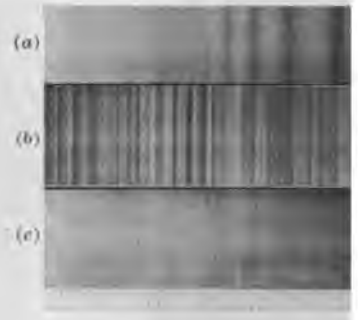


Characteristic Spectra o

Photographed by Yerkes Observato

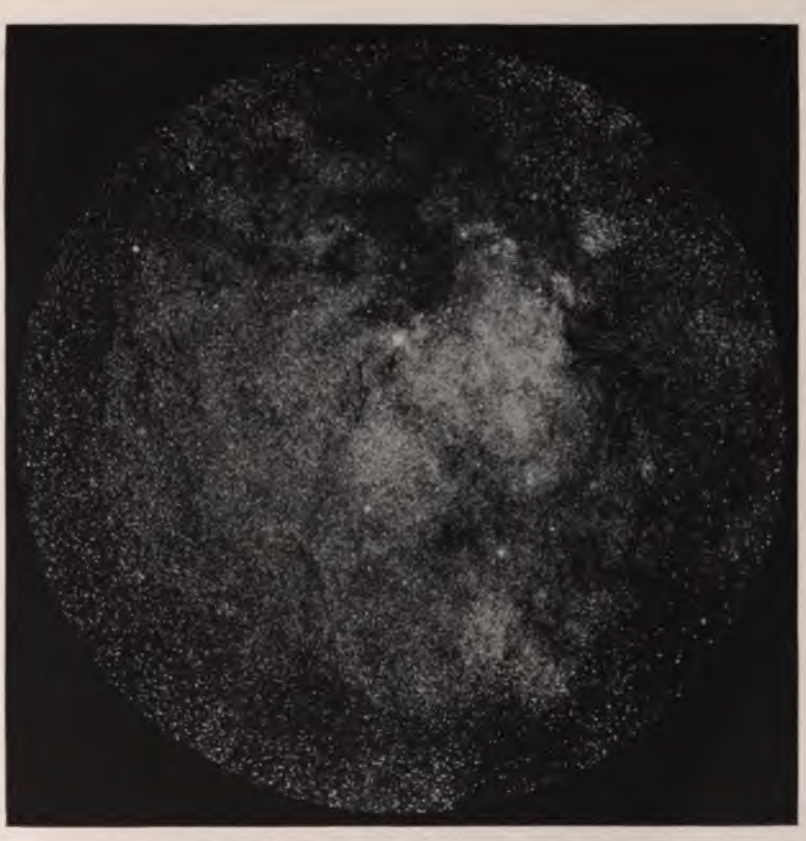
PLATE V

Star Trails Phot

THE BRUCE TE

STAR CLUSTER *Messie*
Small-scale photogr

PLATE IX



STAR CLUSTER *Messier* 11 AND THE SURROUNDING MILKY WAY

Larger-scale photograph taken with 10-inch Bruce telescope (Barnard)

THE MILK
Photographed with

STAR

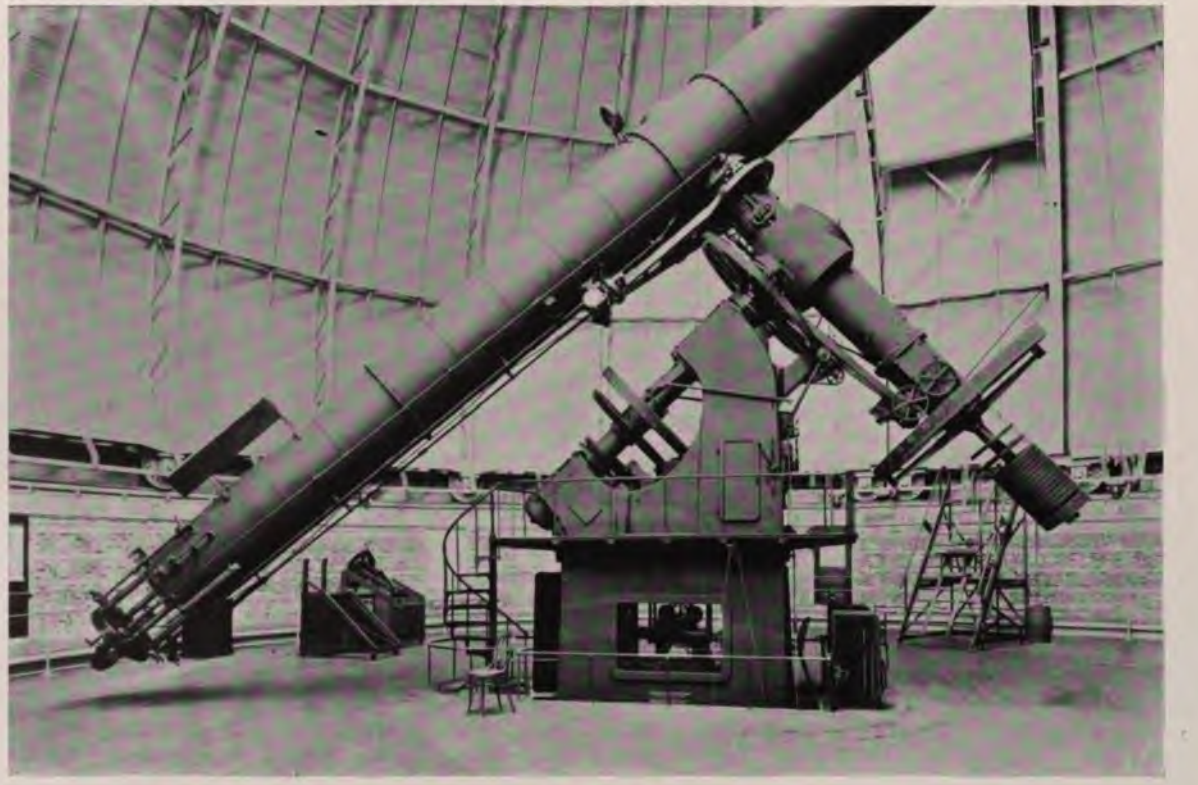
Large-scale photograph ta

Photographed with

Lunar Crater *T*
Photographed with

THE 40-INCH REI

PLATE XV



THE 40-INCH YERKES REFRACTOR
Showing rising-floor at highest position

90-FOOT DO

EYE-END
Showing

THE 24-INCH REFLEC

STAI

Photographed with the 24-in

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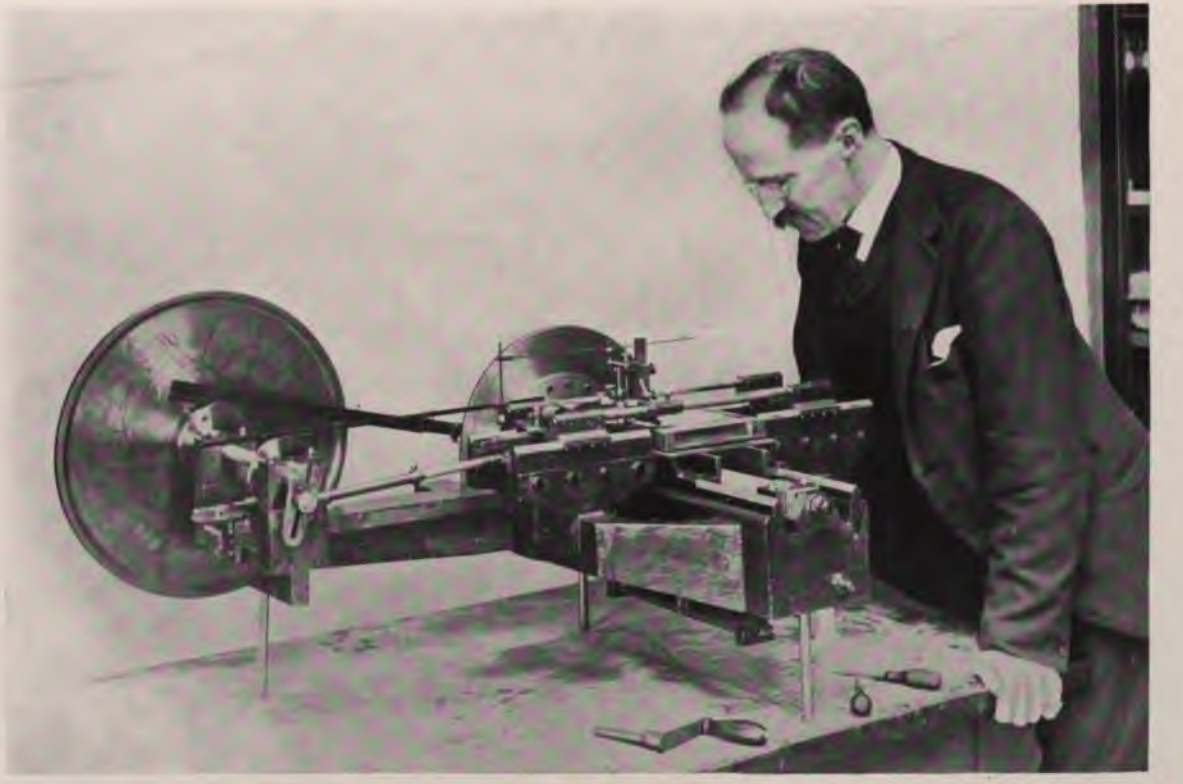
Photographed w

THE

Photographed

PLATE XXII

PLATE XXIV



PROFESSOR HENRY A. ROWLAND WITH HIS RULING ENGINE

PLATE XXV

LANGLEY'S DRAWING OF T

PLATE XXVII

PLATE XXVIII

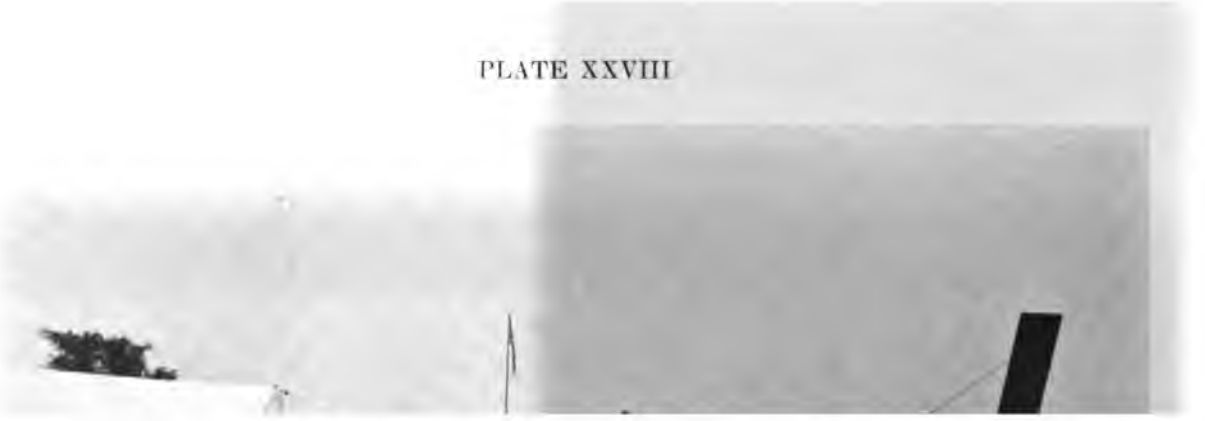
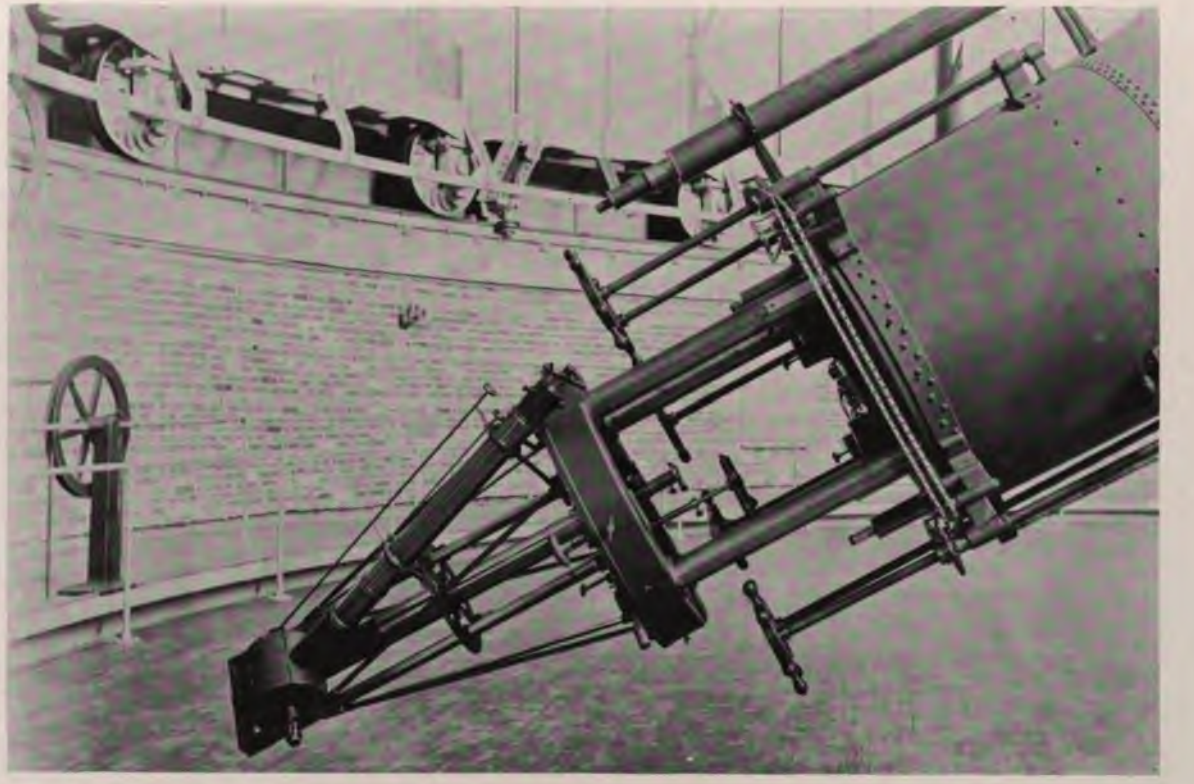


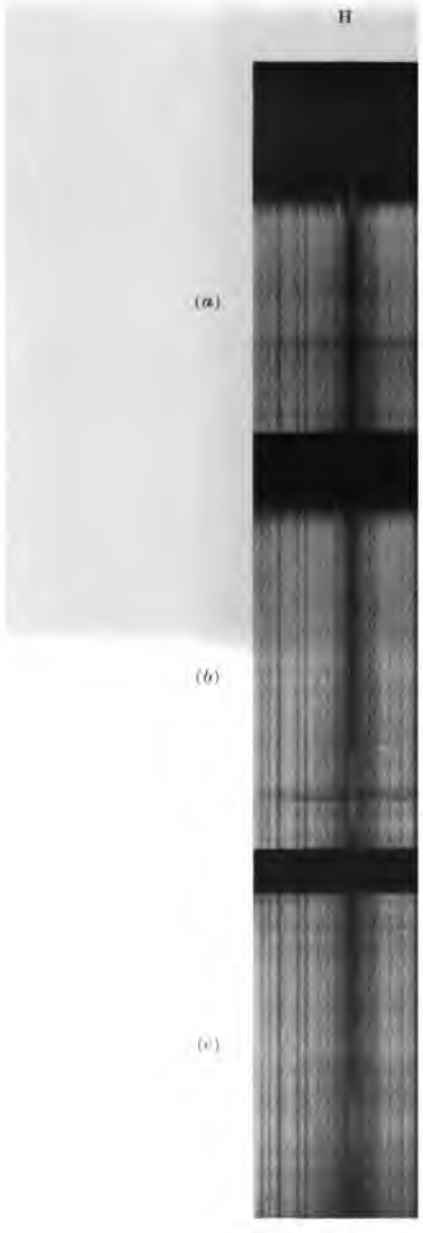
PLATE XXIX

PLATE XXX



Solar Spectroscope Attached to 40-inch Yerkes Refractor

PLATE XXXI



Bright H and K I.
Chromosphere.

PLATE XXXIII

THE KENWOOD OBSERVATORY, CHICAGO, 1888–1895

PLATE XXXIV

Spectroheliograph Attached to 12-inch Kenwood Refractor

PLATE XXXV

ERUPTIVE PROMINENCE PHOTOGRAPHED WITH THE KENWOOD SPECTROHELIOGRAPH

March 25, 1895, $10^h\ 40^m$. Height of prominence, 162,000 miles

PLATE XXXVI

ERUPTIVE PROMINENCE SHOWN IN PLATE XXXV PHOTOGRAPHED 18 MINUTES LATER

Height of prominence, 281,000 miles

PLATE XXXVII

RUMFORD SPECTROHELIOGRAPH ATTACHED TO 40-INCH YERKES REFRACTOR

THE SUN, SHOW
Aug

PLATE XXXIX

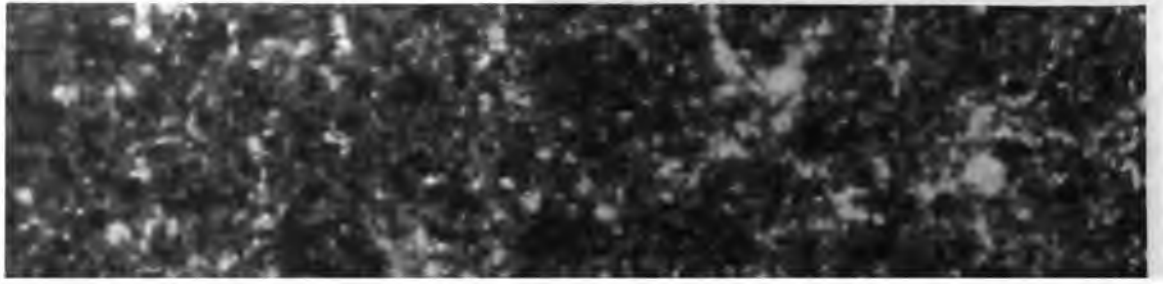


FIG. 1.—

FIG. 2.—3h 31m. Secc

MINUTE STRU

September 22, 1903.

PRISM TRAIN OF TI

H AND K LINES O

PLATE XLII

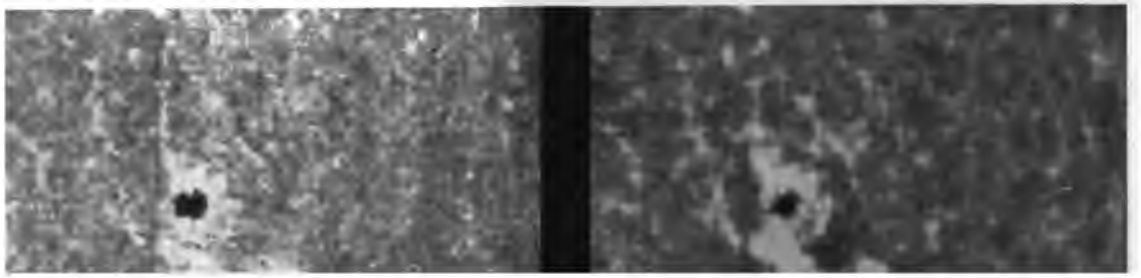


FIG. 1.—3

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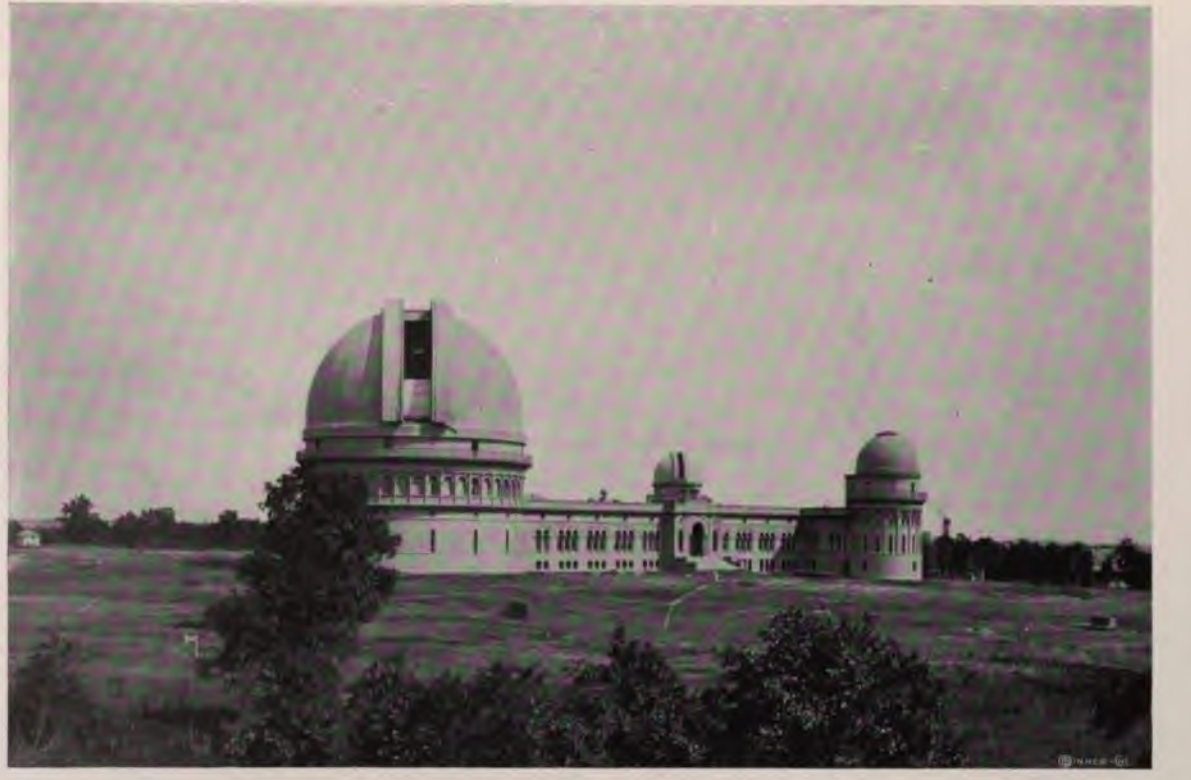
FIG. 2.—11h 0m. Hydrogen fl

PLATE XLIV



THE YERKES OBSERVATORY FROM THE SOUTHWEST

PLATE XLV

ALVAN G. CLARK AND CARL LUNDIN WITH THE CROWN LENS OF THE 40-INCH YERKES OBJECTIVE

THE BRUCE SPECTR
Mounted on its carriag

PLATE XLVII

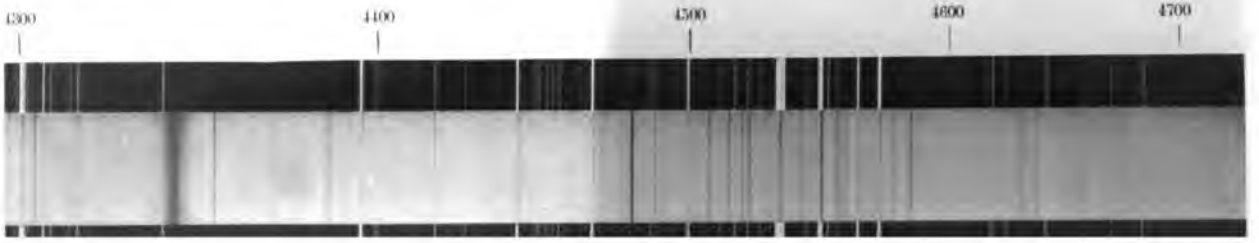


PLATE XLVIII

PLATE XLIX

PLATE L

PLATE LI

PLATE LII

PLATE LIII

PLATE LIV

WIDENING THE "NEW TRAIL"

PLATE LV

SNOW ON MOUNT WILSON

The "Monastery" after the great storm of January, 1907

FIG. 1.—At t

FIG. 2.—
S
Photographe

FIG. 1.—At th

FIG. 2.—

St

Photographe

PLATE LVII

PLATE LVIII

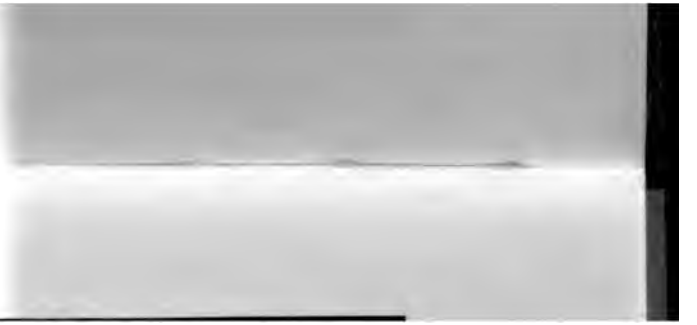
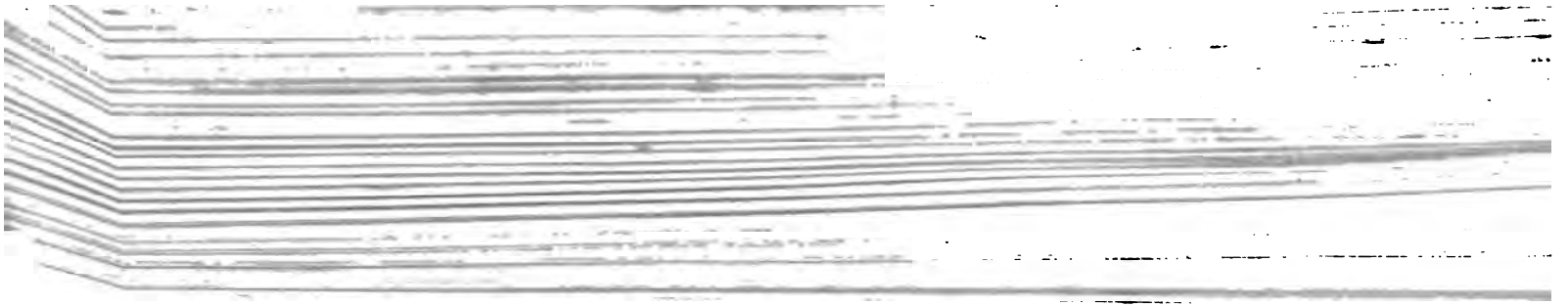
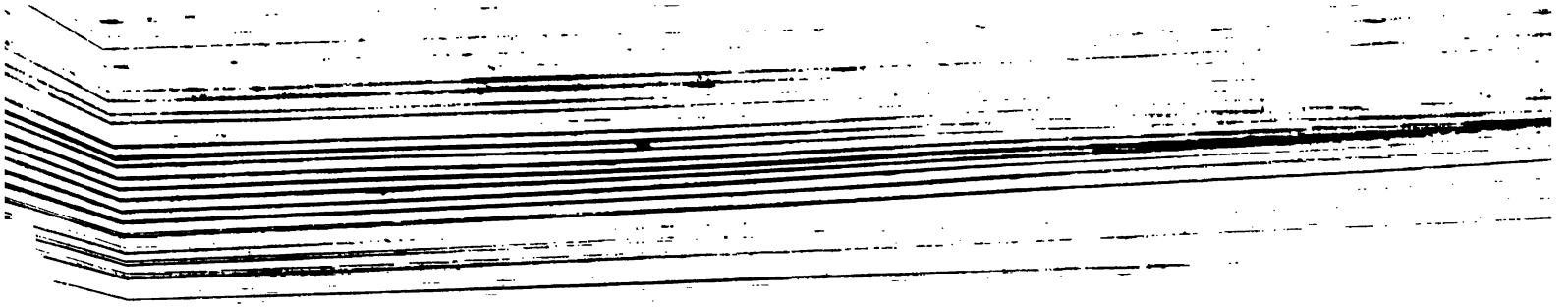
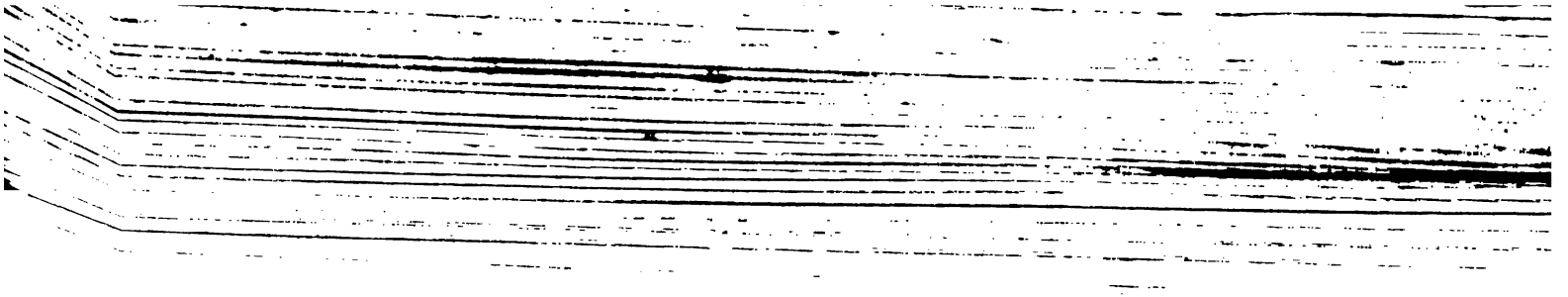
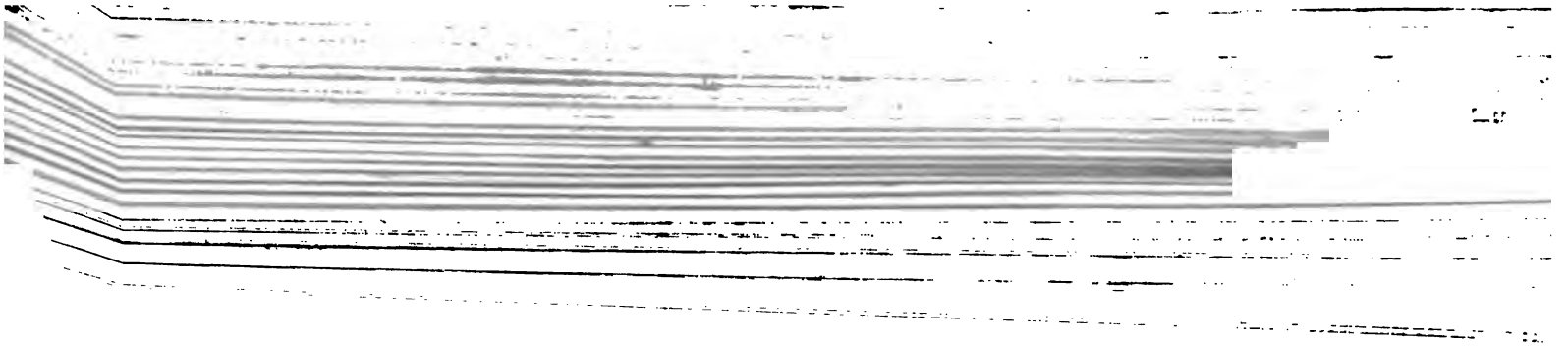


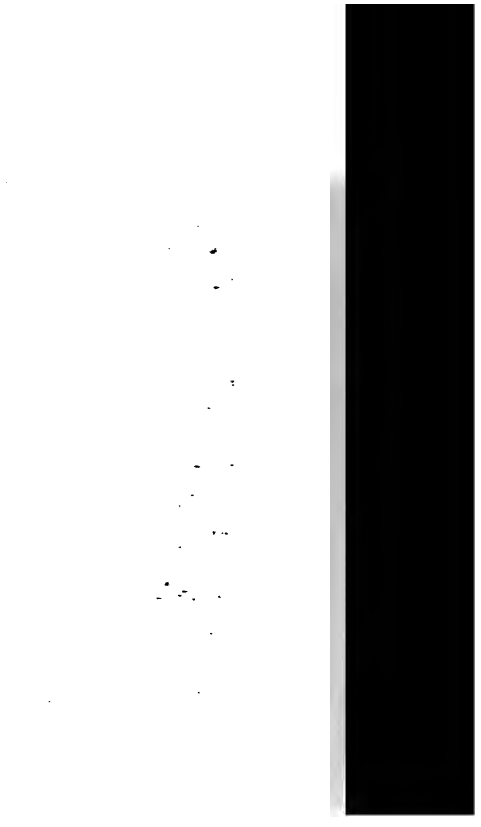
PLATE LIX

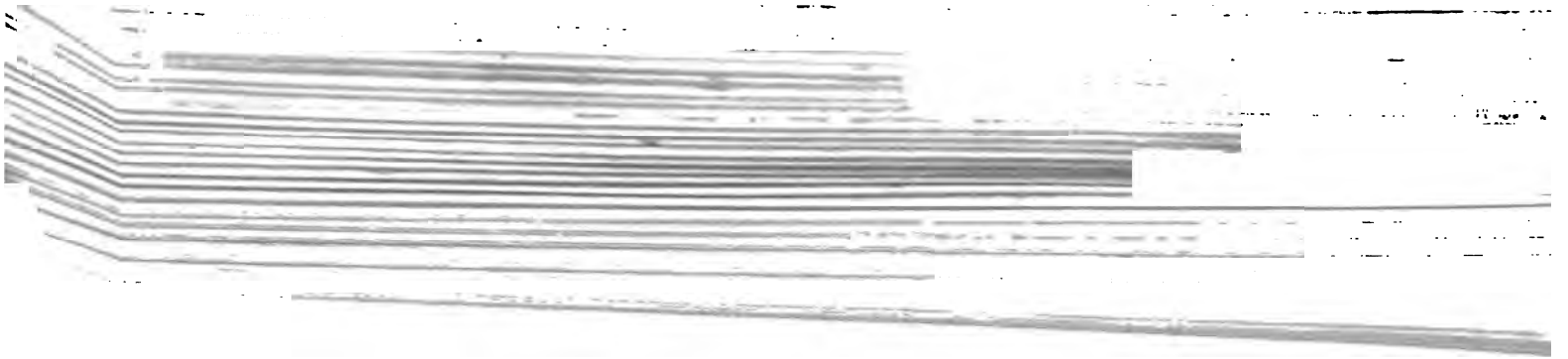


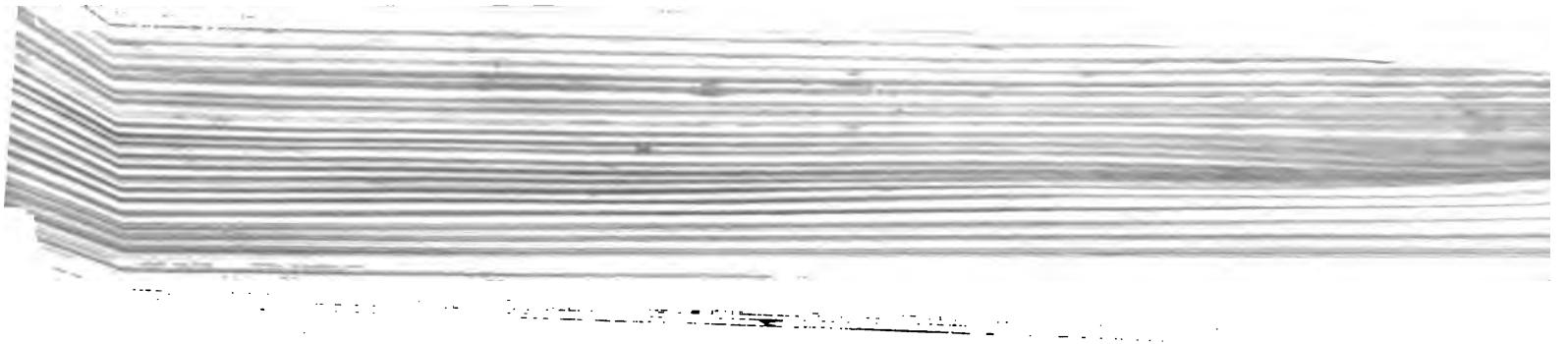


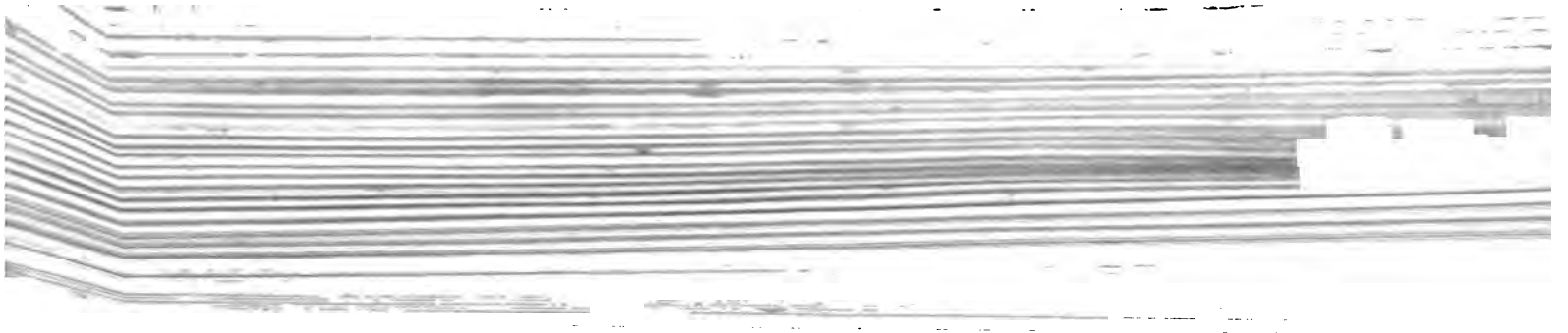


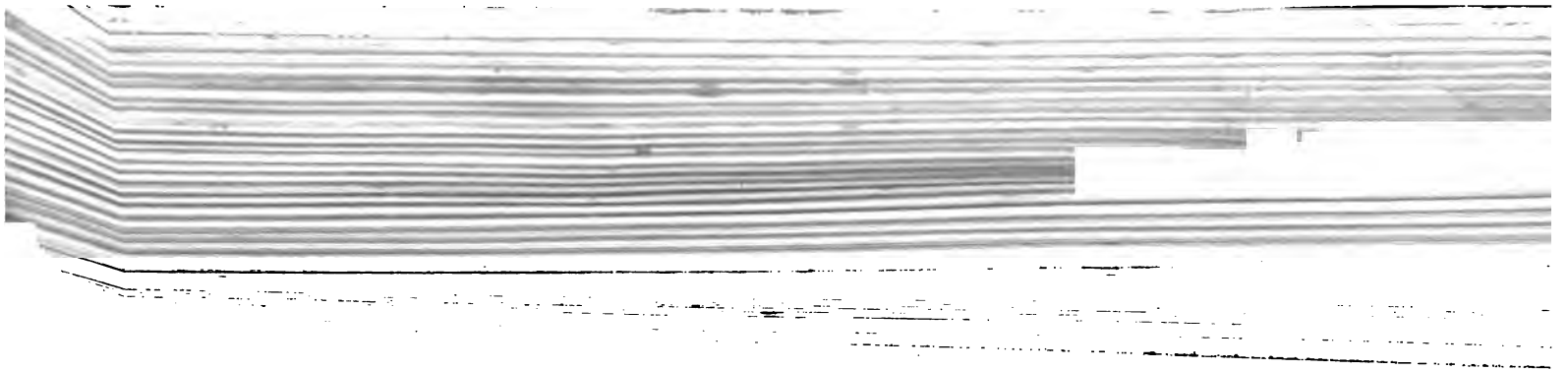


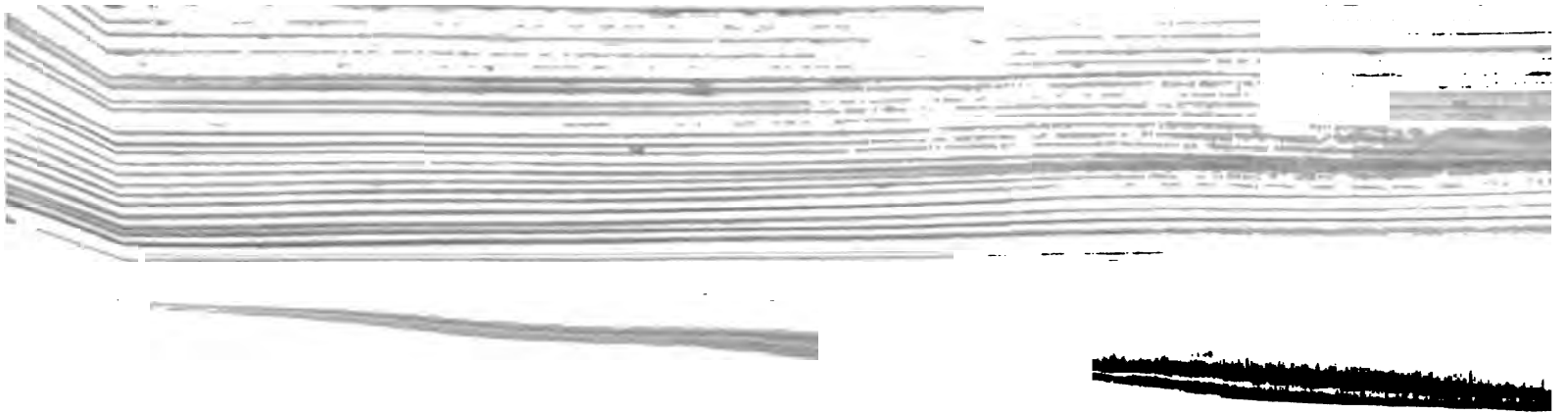












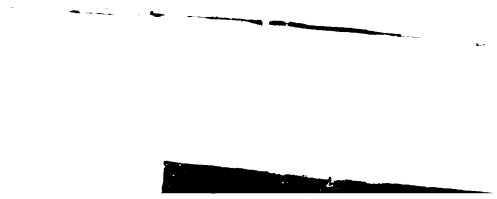


PLATE LXXIII

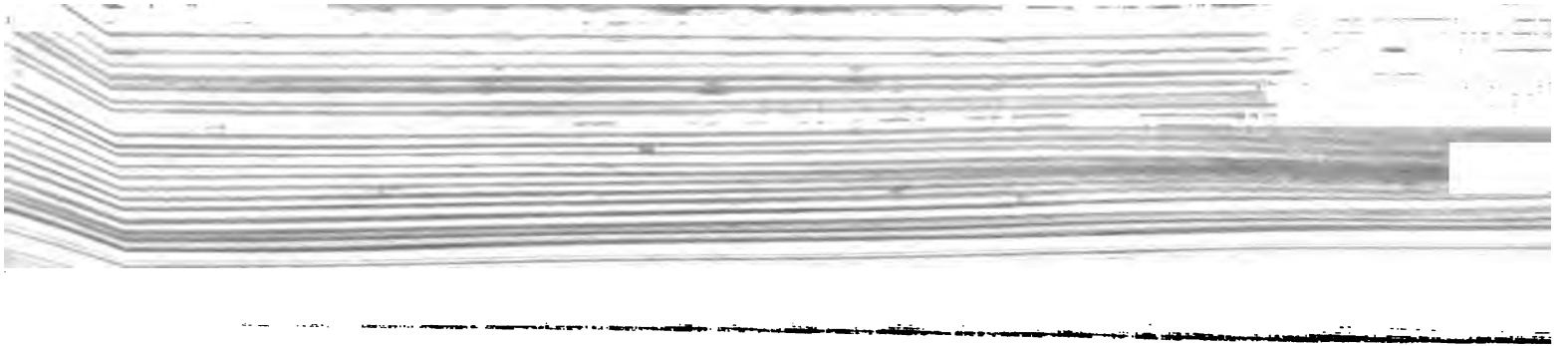
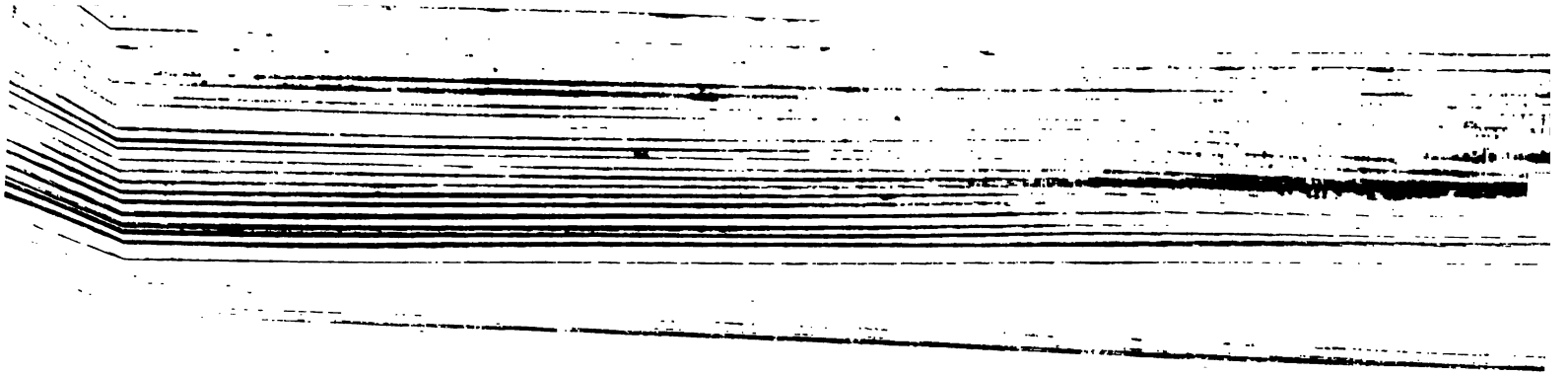


PLATE LXXV



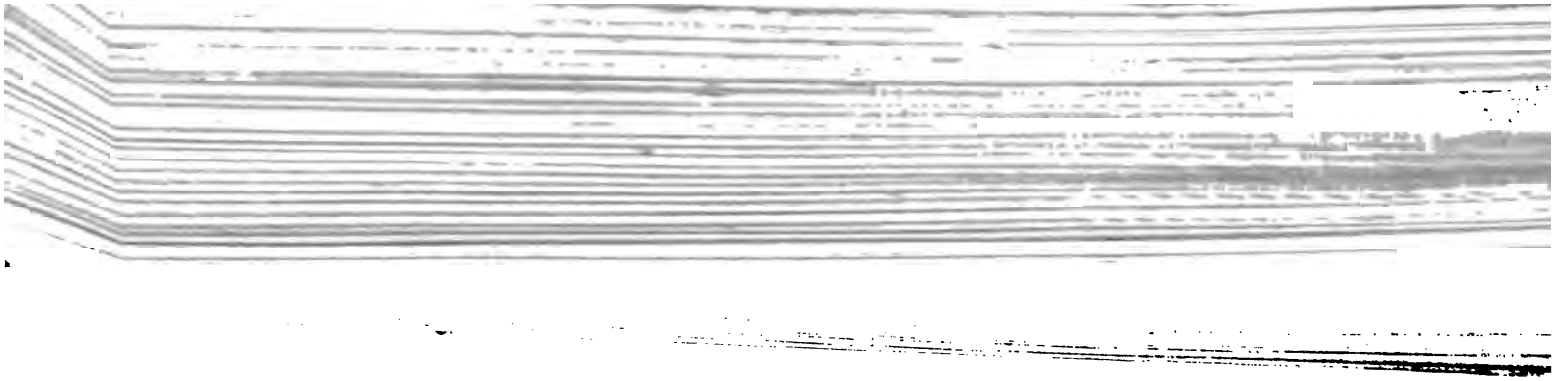


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PLATE LV

PLATE LXXVIII

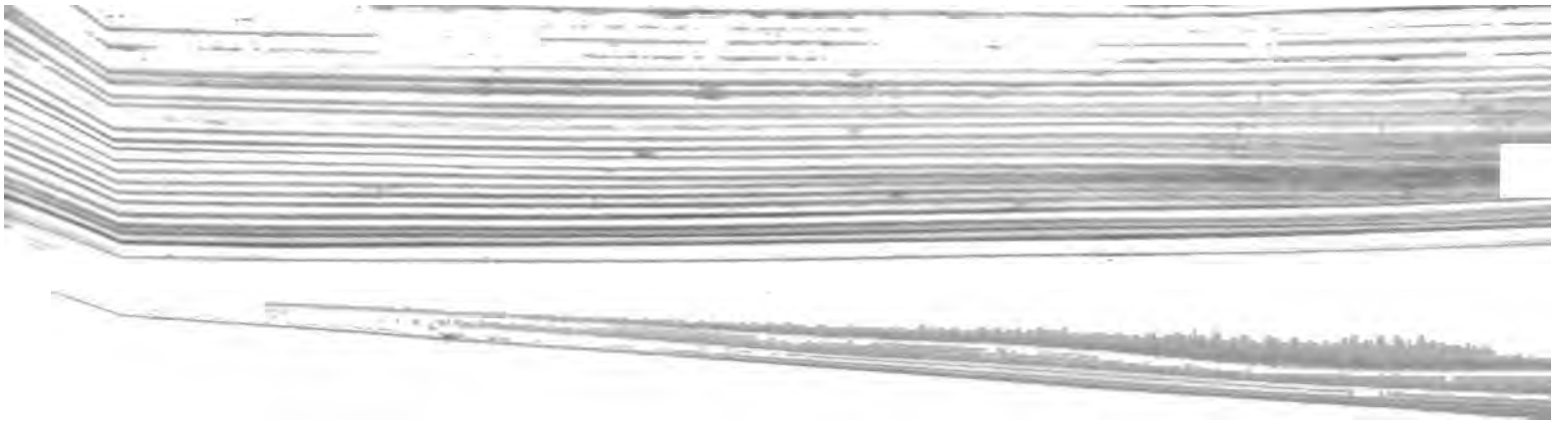
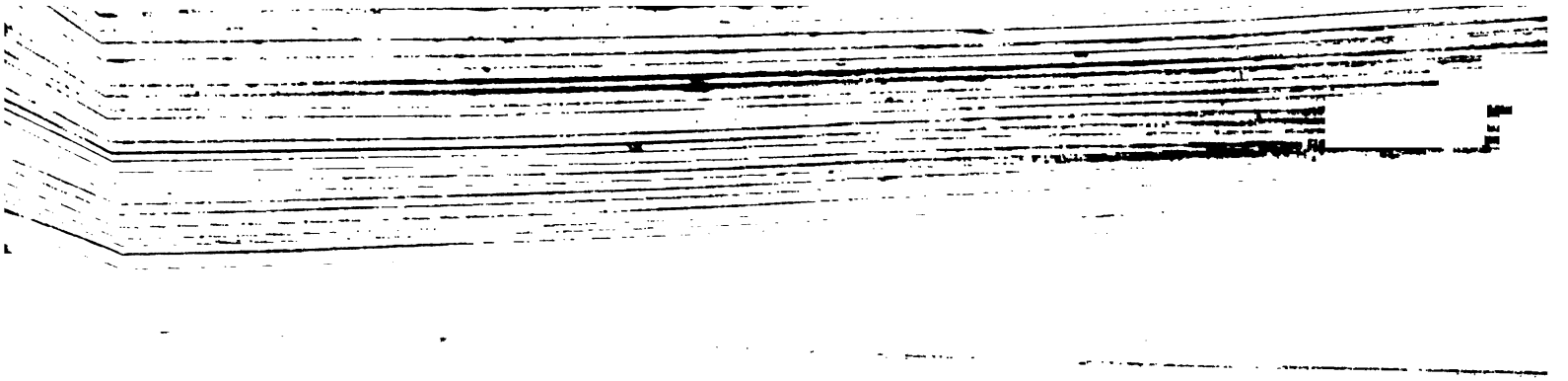
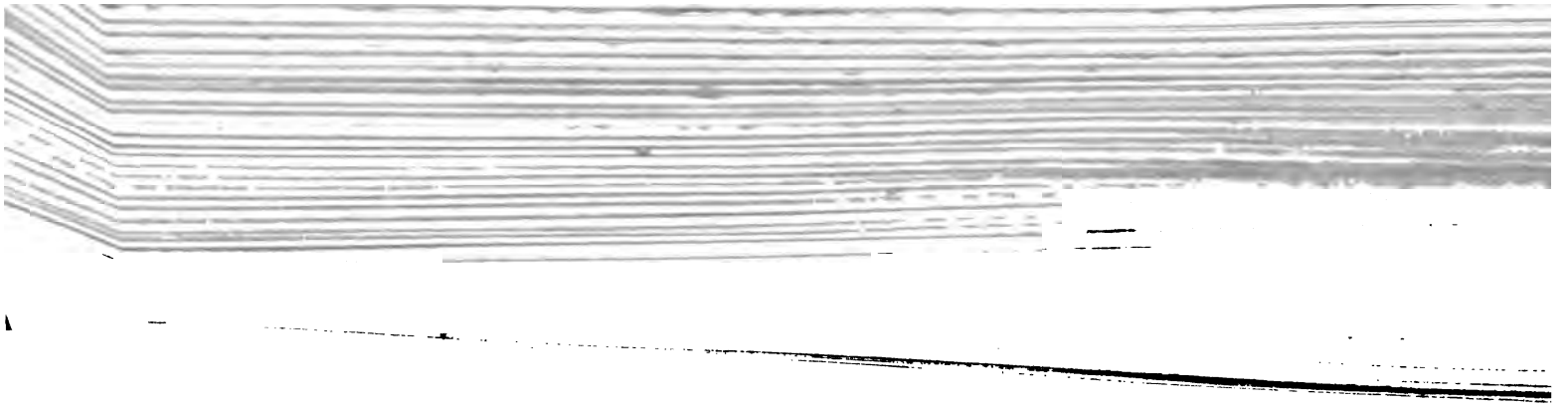
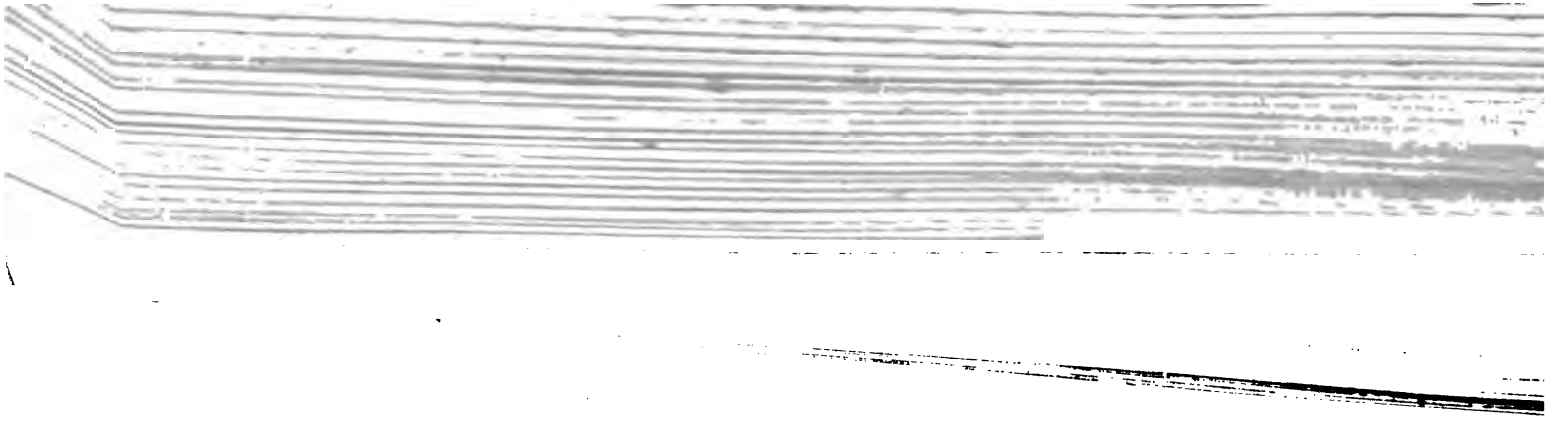
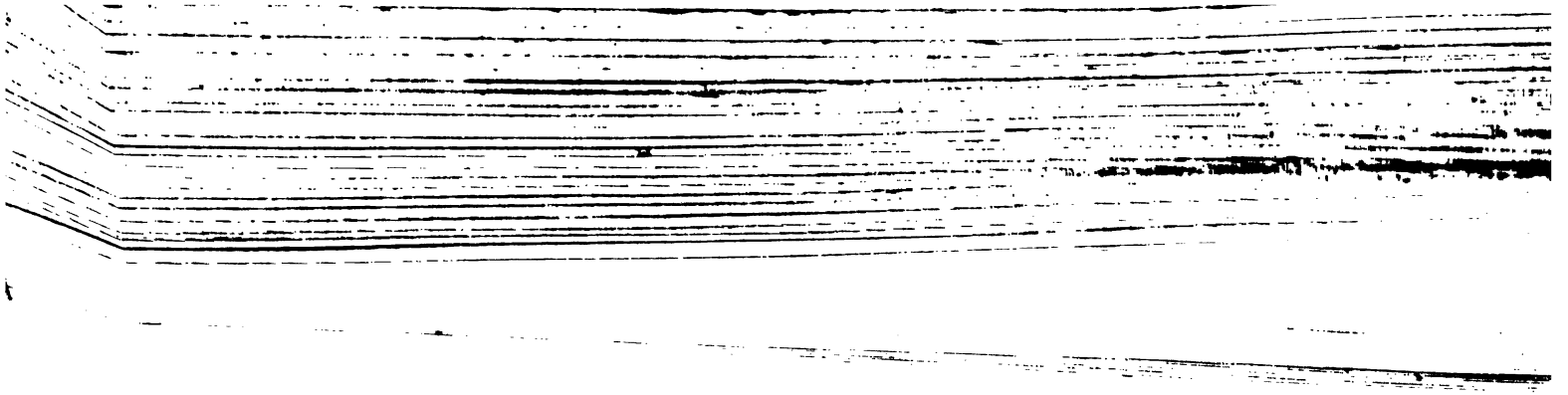


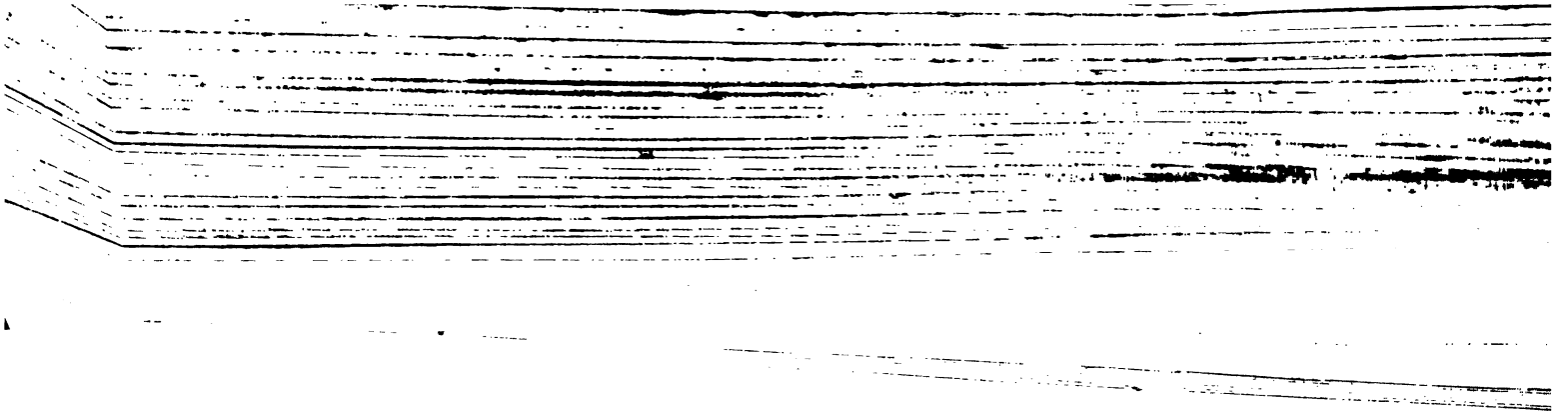
PLATE LXXIX











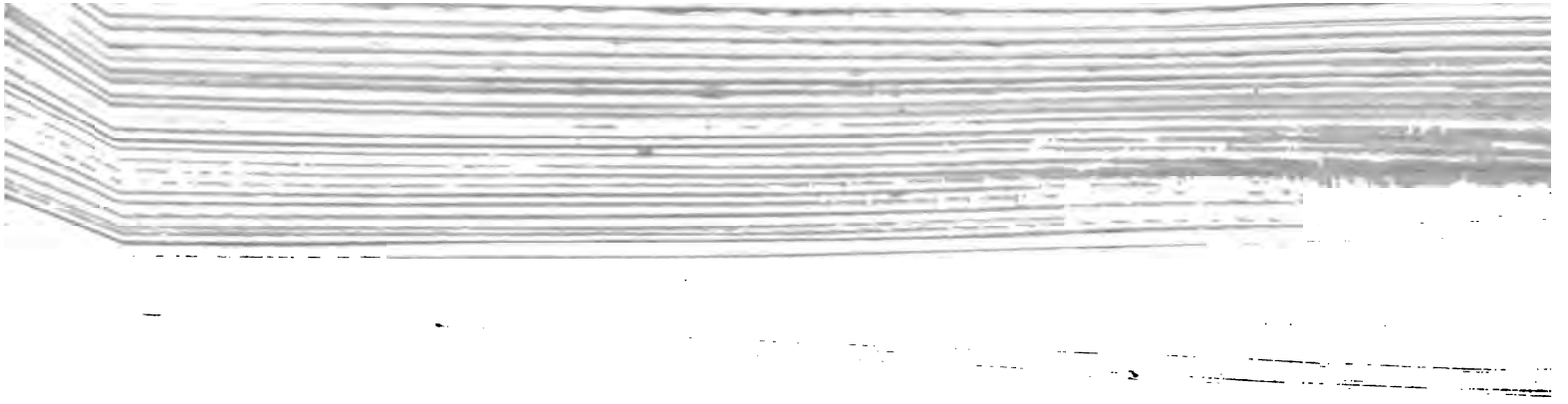
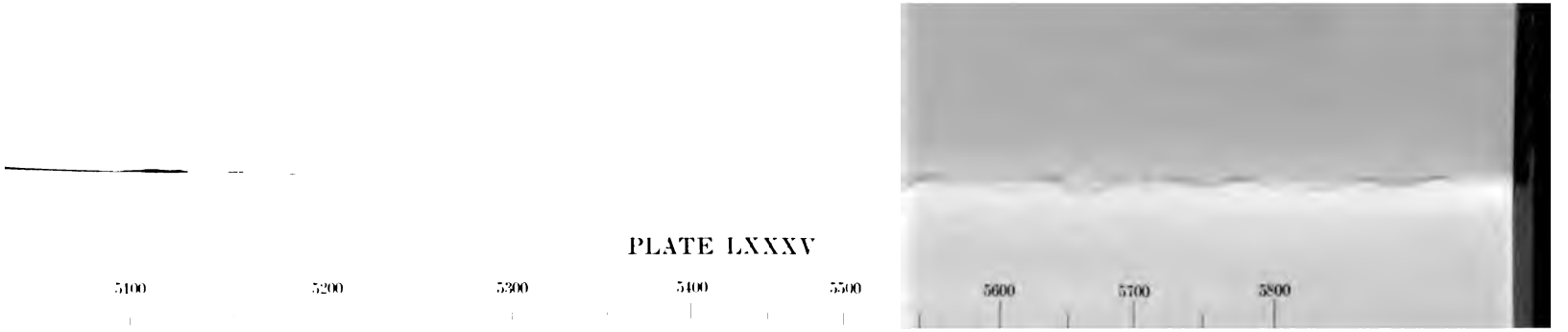
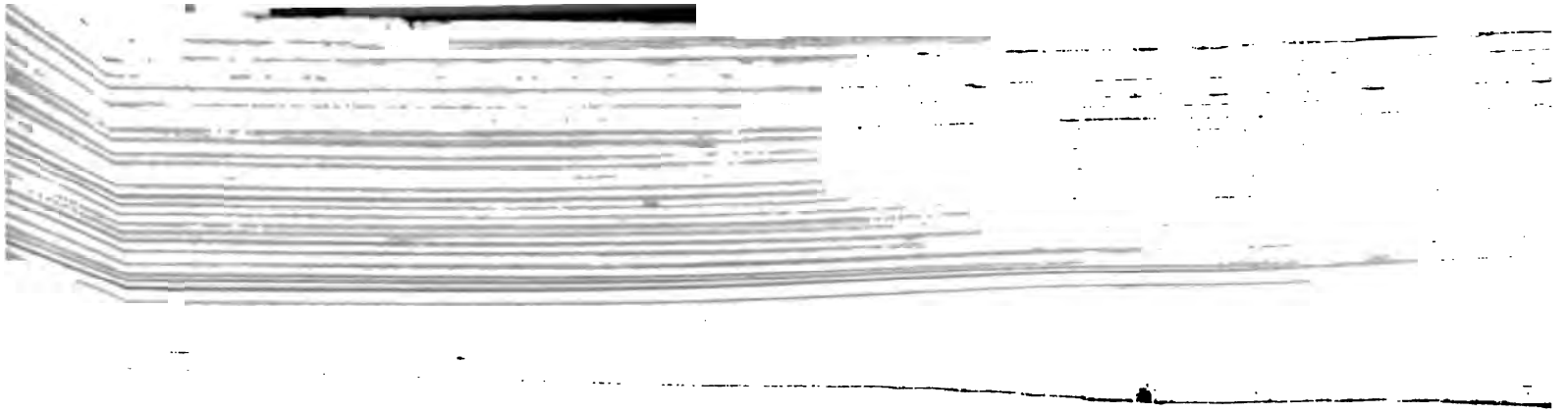


PLATE LXXXV





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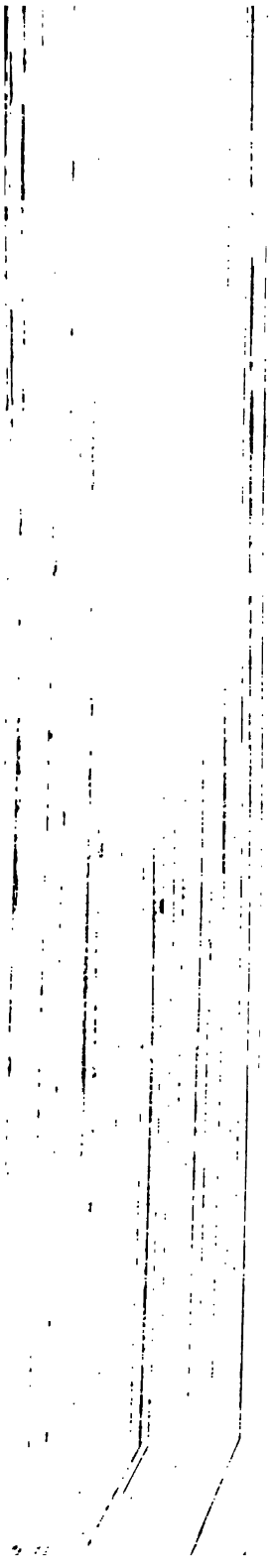
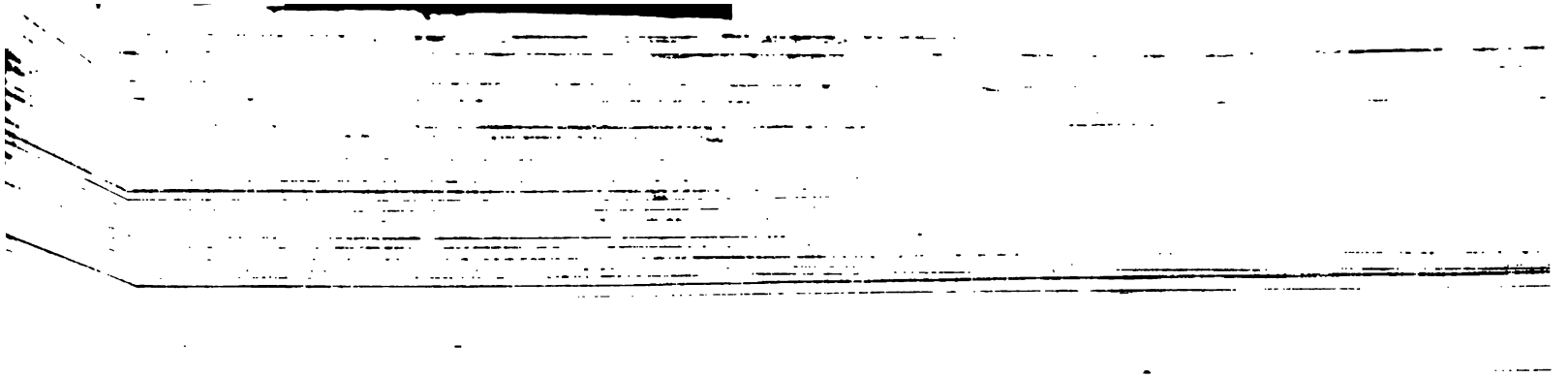
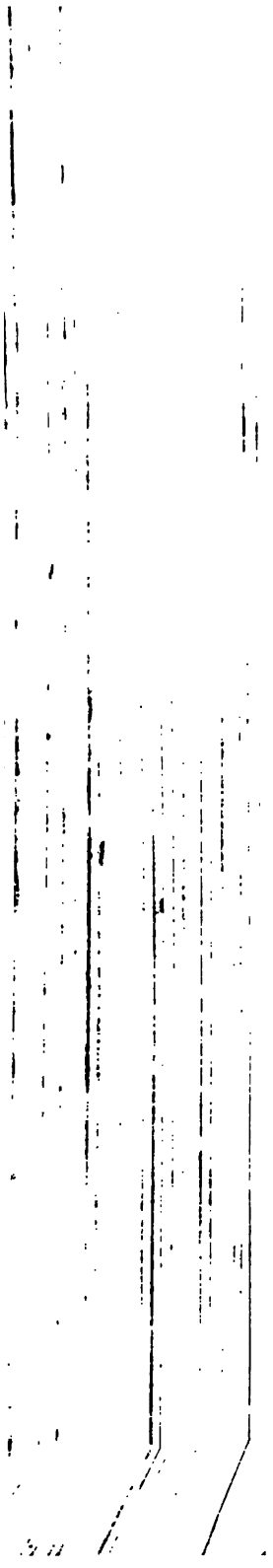






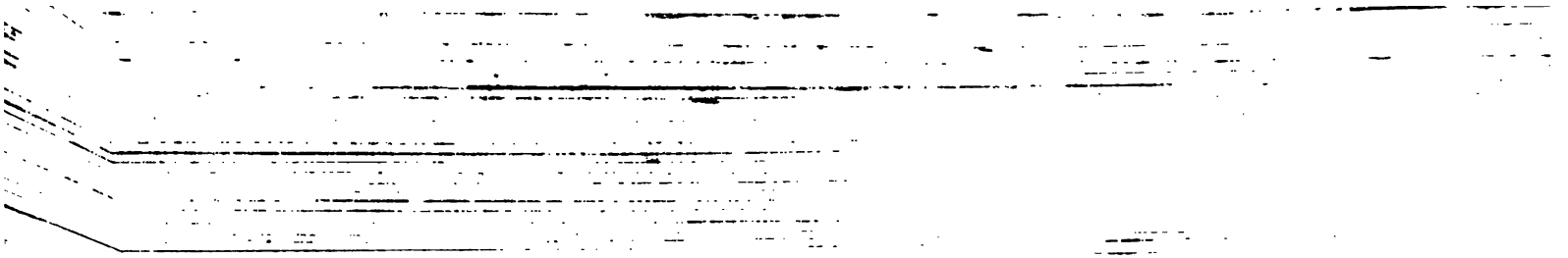


PLATE XCI

PLATE XCII

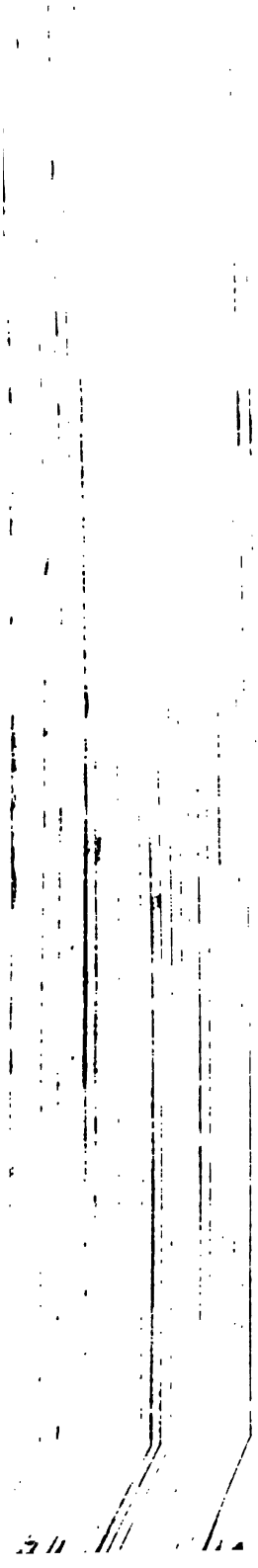
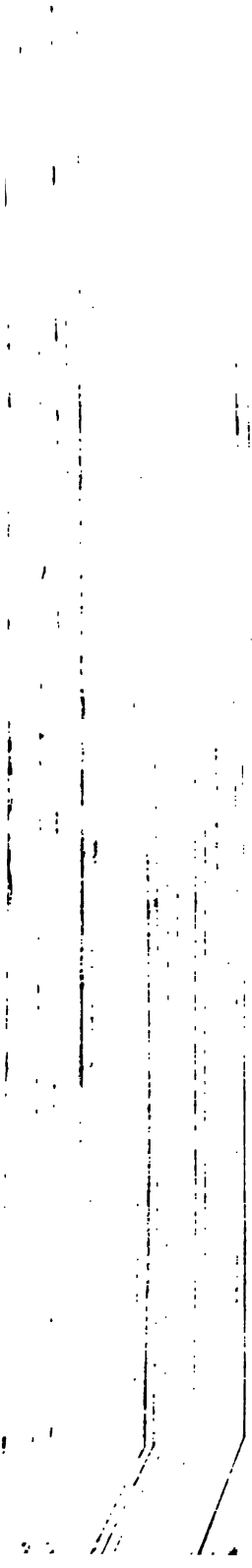
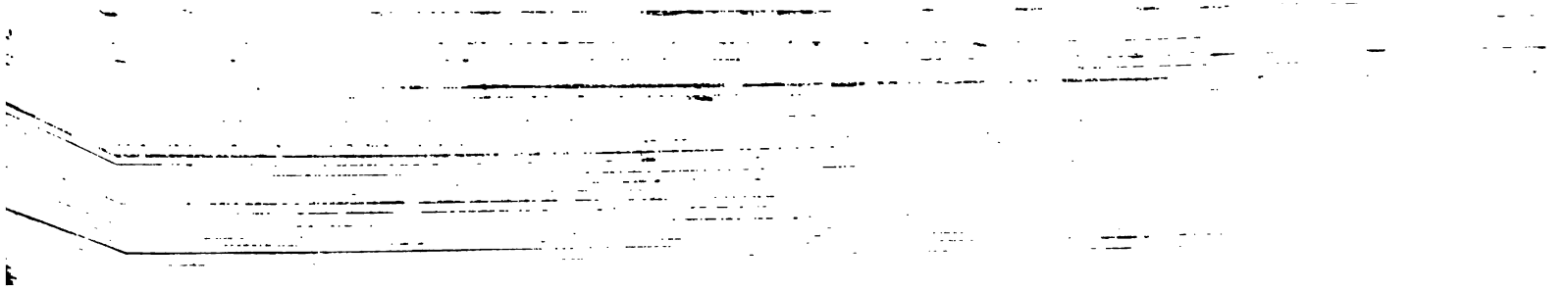


PLATE XCIII





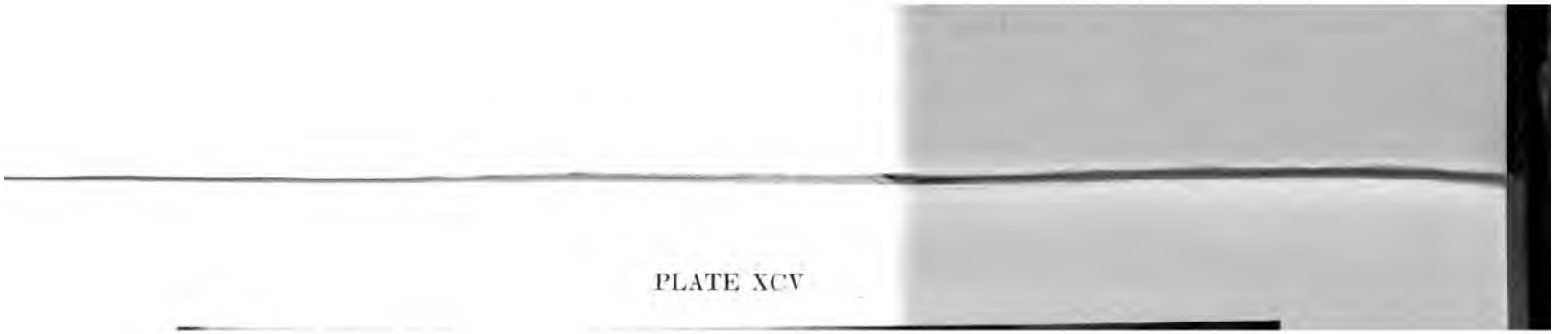


PLATE XCV

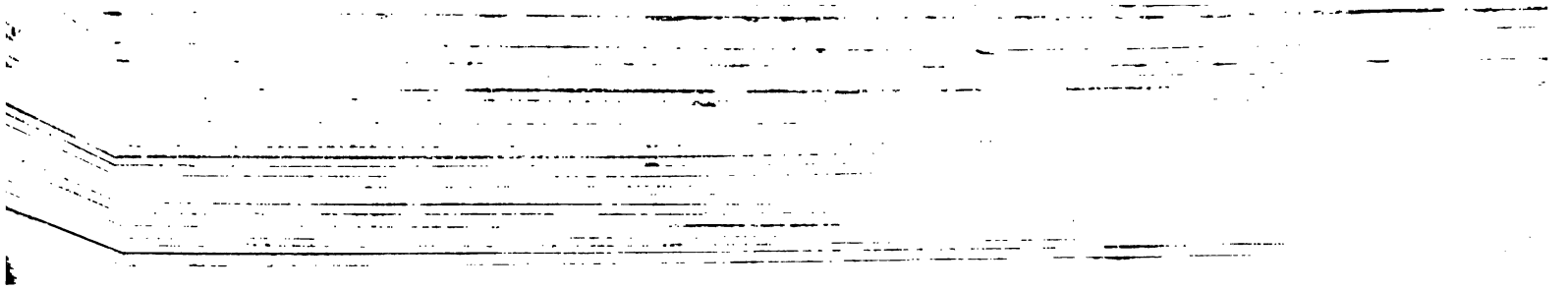
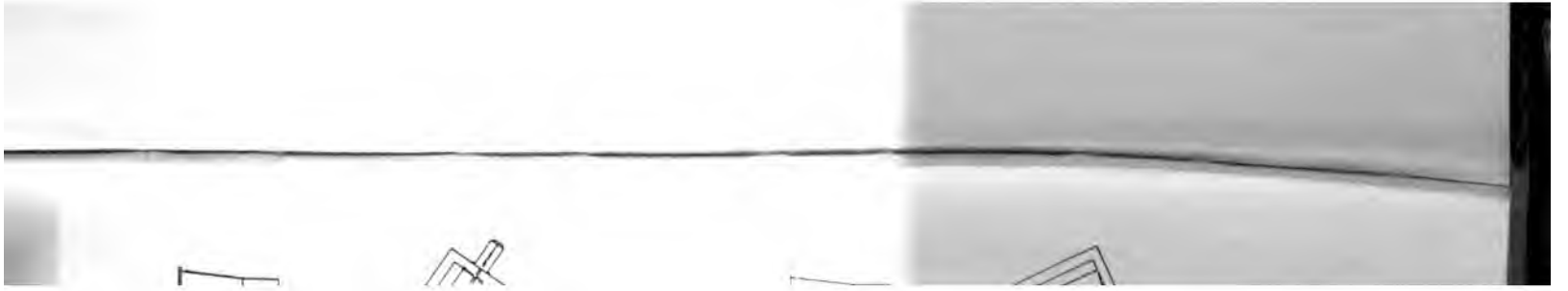
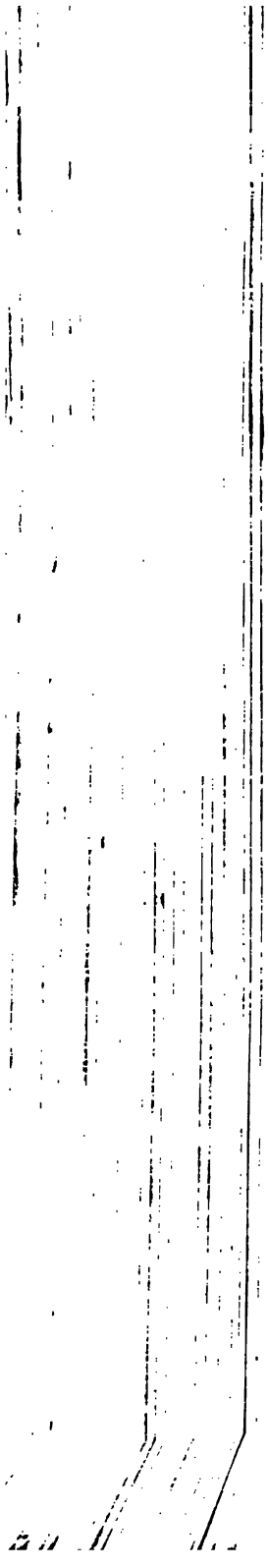
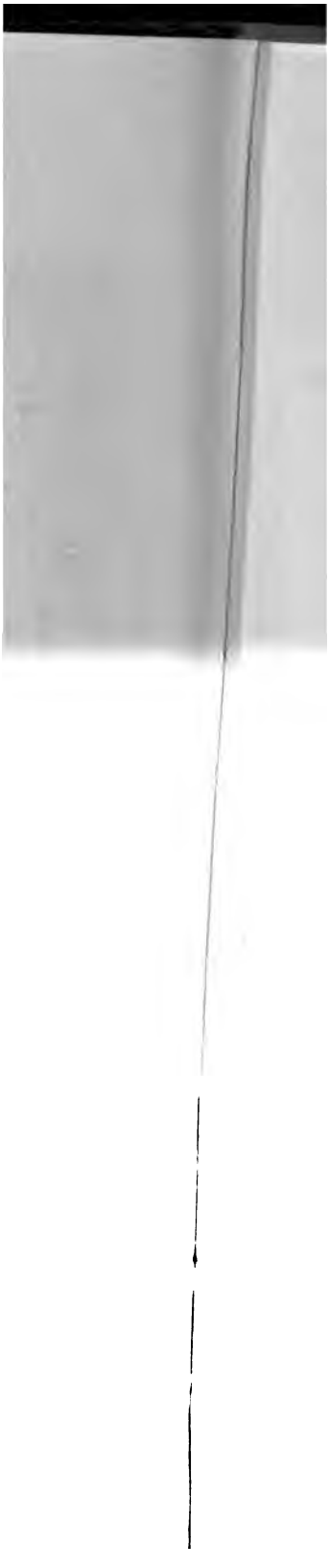
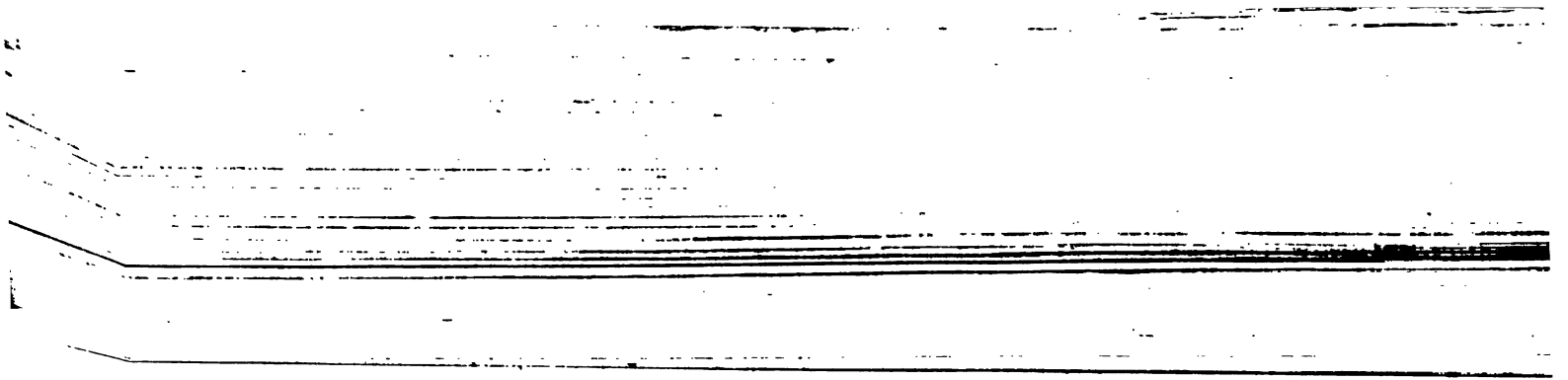


PLATE XCVI









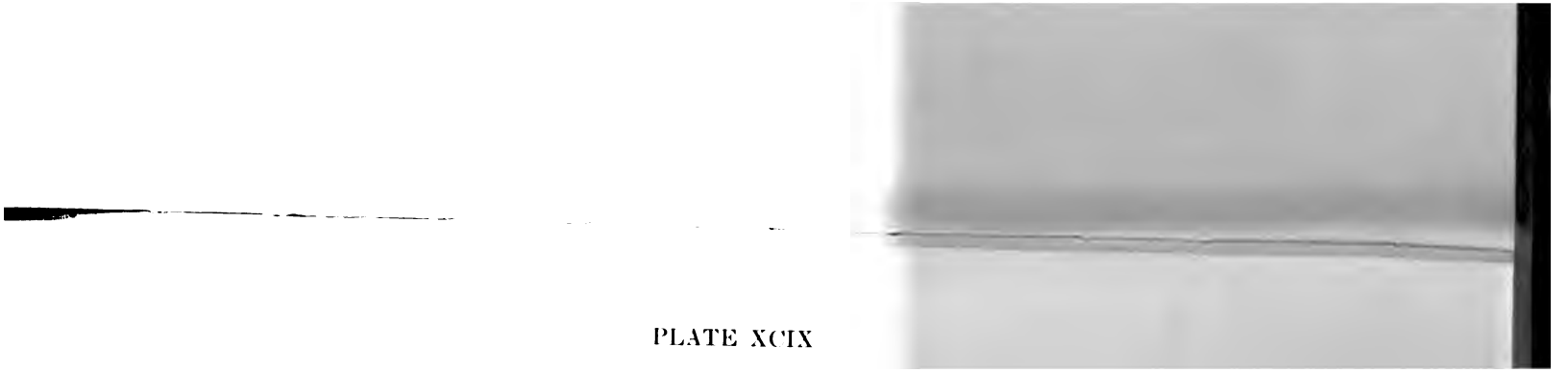
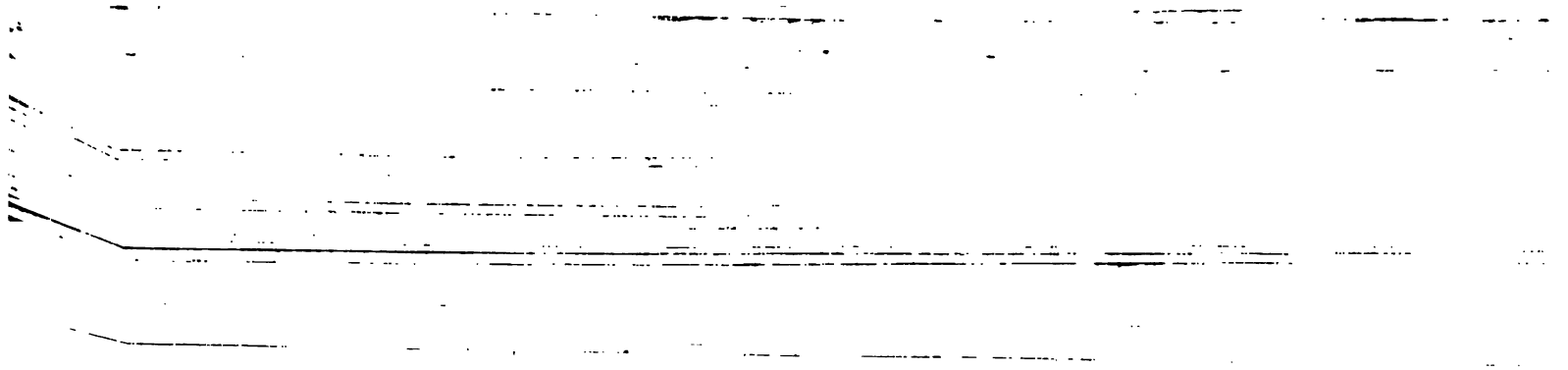


PLATE XCIX



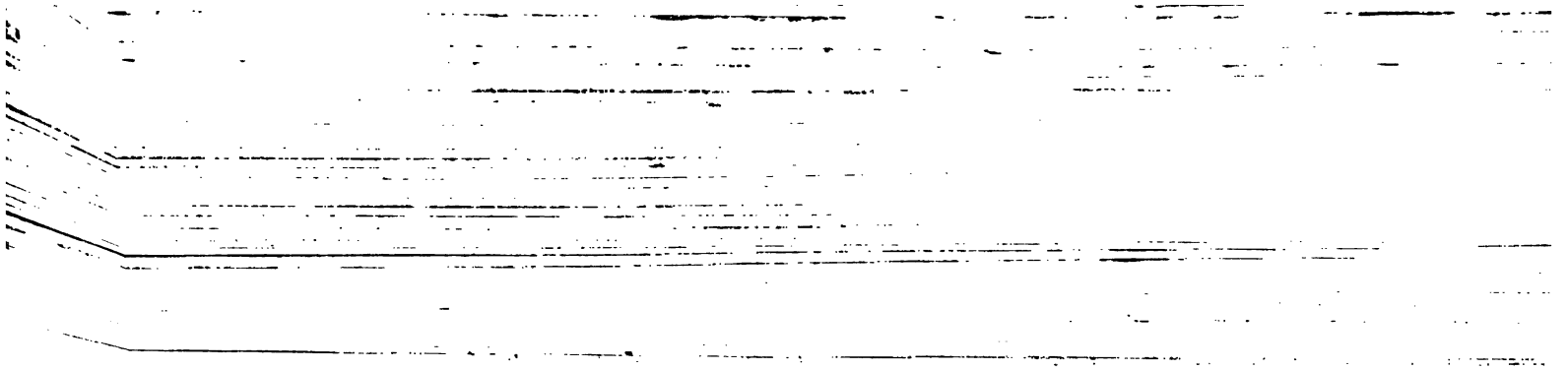


PLATE CI

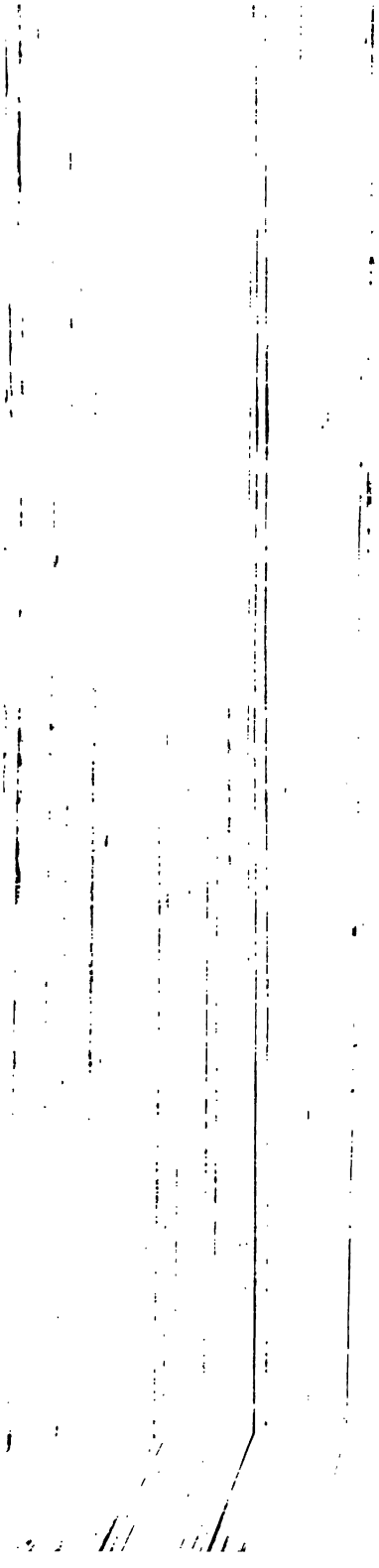


PLATE CII

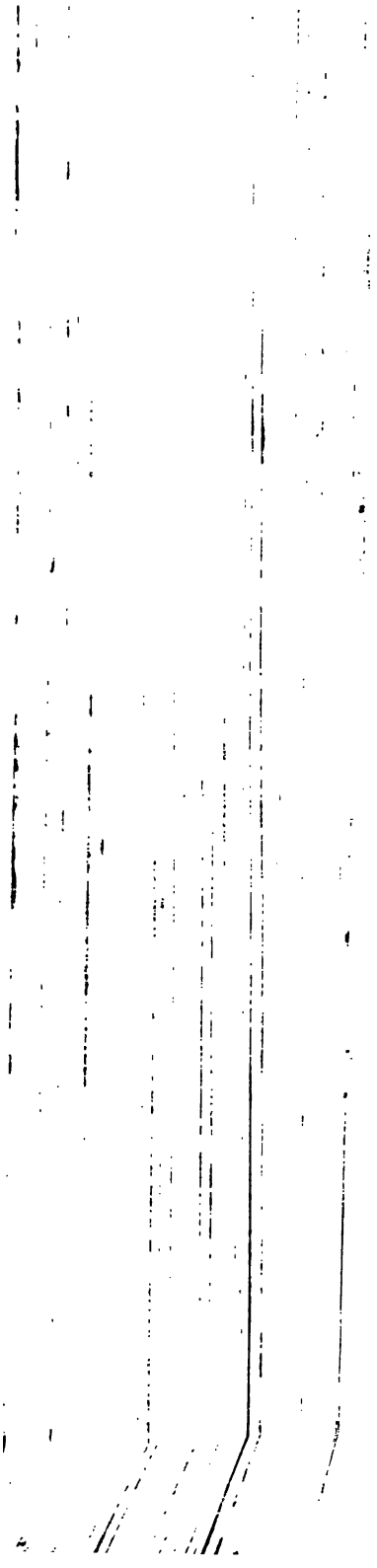


PLATE CIII

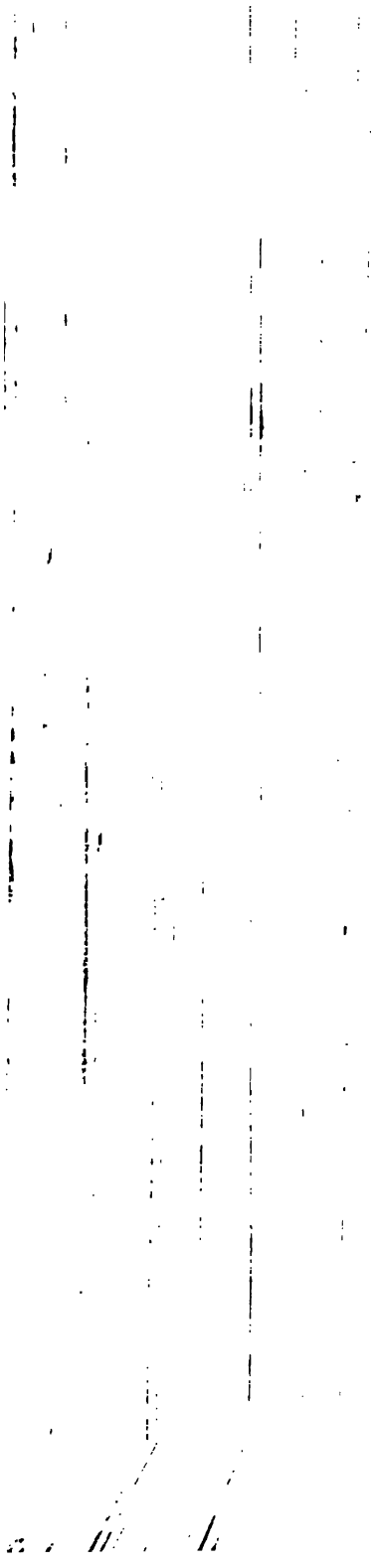
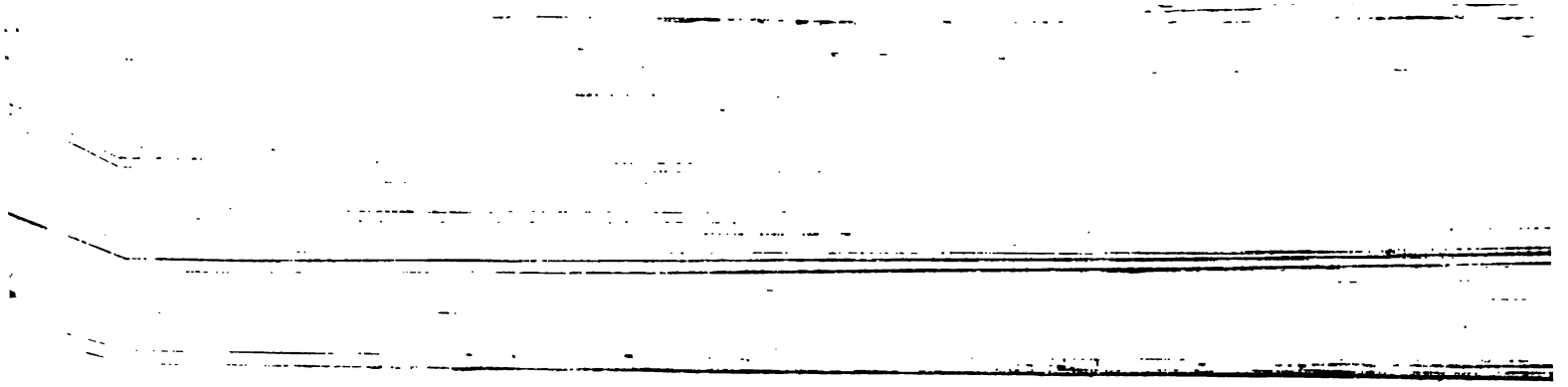



PLATE CIV